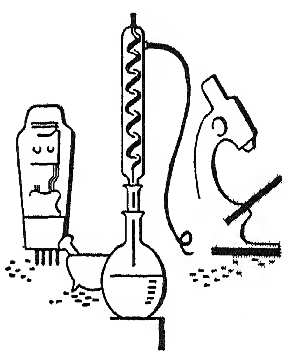

Boeing Airplane Co.

Full-power take-off of a big jet bomber.

THE BOOK OF
POPULAR SCIENCE



volume 6

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ACCIDENT PREVENTION IN THE HOME

Safety Rules for All Members of the Family

by

GLADYS J. WARD

WE commonly think of the home as a place of refuge, where we are safe from the thousand and one dangers that confront us on the highways and byways. And yet, like so many popular ideas, this one does not hold water. The average home is one of the most dangerous places in the world; within its walls lurk the hazards of broken bones, electric shock, burns, poisoning and a host of other dangers. In a recent year, 35,000 Americans lost their lives because of accidents in their own homes. Over 5,000,000 more were hurt; and of these 140,000 suffered permanent injury. A great many of the tragedies happened to small children; they were the chief victims in home fires and in cases of poisoning.

The majority of accidents at home are due to carelessness; they are caused in the main by articles that are out of place or in need of repair. That means that the majority of accidents are preventable. We should seek out all possible sources of accidents and should work out a systematic plan for avoiding them. An ounce of prevention is certainly worth the proverbial pound of cure.

Fires and explosions

Fire is a useful servant; it may also become a ferocious enemy. Under control, in a furnace or stove, it keeps our buildings warm and cooks our food. But when fire gets out of hand, it is a dangerous foe. It strikes quickly and spreads with amazing speed; it may cause agonizing injury or death. It may destroy a house, a neighborhood, a town.

Three things — fuel, heat and oxygen — are necessary to start a fire. The fuel may be the coal or oil or gas used for heating purposes; or it may be an inflammable cleaning fluid, or waste paper stored in a basement or attic. The heat may be provided by a lighted gas burner or match or an overheated electric wire. The oxygen is always available, since roughly one-fifth of the air is made up of this gas.

We can do nothing, of course, about eliminating oxygen in the home, since we need it for breathing purposes. But we should see to it that temperatures high enough to cause fires are restricted to our cooking and heating units; we should see to it, also, that potential fuels, other than those used for heating and cooking, are kept away from extreme heat.

More dangerous fires start in the basement than anywhere else, since the furnace and the hot-water heater are usually placed there. Hence we should regularly and carefully inspect our heating equipment. Furnaces should be installed at a safe distance from wooden partitions, beams or ceilings; and furnace ducts should be at least one inch away from these. A pipe passing through a wall or floor should be encased in a metal tube an inch larger in diameter than the pipe; this tube should be provided with tight metal caps at either side of the wall or floor.

The house heating system should be large enough to heat the home comfortably. A heater that is too small may be a hazard because it may be necessary to overfire the furnace in cold weather. The heating system should be equipped with ample safety controls. Each boiler should have a device limiting the temperature of the water to a safe point. For a gas-fired boiler the principal control is the gas pilot safety device, which shuts off the gas supply if the pilot light is not burning. For oil furnaces there is a safety combustion control, which prevents the continuous pumping of

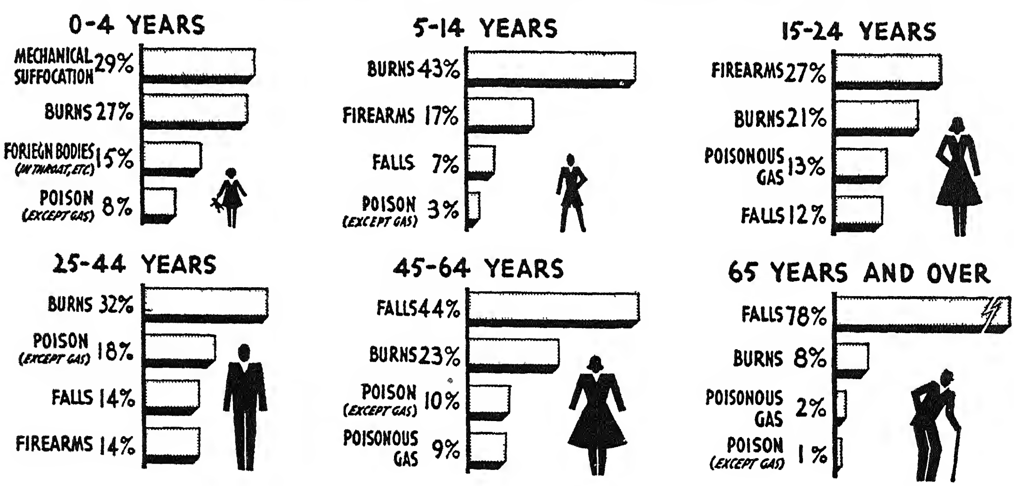
oil when the flame fails to ignite. It is hardly necessary to point out how dangerous it is to let your cellar be flooded with highly combustible fuel oil

The illuminating gas used in cooking ranges, and in certain heating units, is highly explosive. If it escapes from the range or from a leaky pipe it may set the stage for a grim disaster, for the slightest spark will explode it. Should there be the faintest odor of unburned gas anywhere in the house, put out all flames. Never strike a match in order to locate the leak; use a flashlight Open the windows wide; then call your gas company if you can not locate the source of the smell

on the gas and lighting the match. Keep a watchful eye on any pots or kettles containing a liquid that is about to come to a boil. If it should boil over and put out the flame, gas would be set free. If such a thing happens, turn off the gas immediately and open the windows for a few minutes before relighting the burner. Never hang window curtains too near the range, since the draft from an open window might blow them on the flame.

Fire may sometimes break out when a house is struck by lightning. Carefully installed lightning rods on the house and near-by buildings will help to prevent fires by grounding the electricity during storms.

PRINCIPAL TYPES OF HOME ACCIDENT FATALITIES IN 1947



● Source National Safety Council approximations based on data for 1947 from National Office of Vital Statistics

Sometimes the pilot light on a kitchen range becomes blocked up; it then goes out, allowing gas to escape. Clean the pilot light carefully, using a fine wire about the size of a hairpin. Burner cocks that become loose should be repaired or replaced at once, to avoid leaks. There is always the danger, too, that one may turn on a cock without noticing it.

Keep the surface and oven burners on gas and kerosene ranges clean and free of burned food. Light the gas oven according to the manufacturer's directions. Open the oven door to let air in before turning

If a television antenna has been installed on your roof, be sure that it has been properly grounded.

Misused or faulty electrical equipment is another common cause of fire. The trouble may come from electric wires that are exposed to a heavier current than they can safely carry; as a result, they become overheated. Fuses are inserted in each electric circuit to prevent such an occurrence Each fuse generally consists of a strip of a bismuth alloy, with a remarkably low melting point. When the current becomes too strong for the wires, the heat causes the

alloy to melt and thus breaks the circuit

If a fuse blows (melts) on a given circuit, it may simply mean that you have been using too many pieces of electrical equipment at the same time But if the fuse on this circuit blows again and again, it provides a warning that you should not ignore. Have a competent electrician check your wiring system; he may find it advisable to install heavier wiring or to add a circuit or two to the ones you already have.

Always have the wiring system checked before buying heavy electrical equipment You may find it necessary to install special heavy-duty wire for the electric range, clothes dryer and ironing machine Use electrical appliances and cords according to the written directions that accompany the equipment. Light sockets are made for lighting purposes; appliances such as irons should be plugged into appliance outlets — never into light sockets When disconnecting any appliance, pull on the plug, never on the cord

Worn-out cords can also lead to trouble. It is a dangerous practice to run cords under rugs, over radiators or through door jambs, since this causes undue wear. Promptly repair or replace frayed cords.

Inflammable liquids are a constant fire hazard

Inflammable liquids like gasoline, kerosene, oils, paint and turpentine are a constant fire hazard. Of course we should never under any circumstances store gasoline inside a house. If we must keep kerosene cans there, we should be sure that they are tightly closed, clearly labeled and stored far away from all sources of heat. Avoid the dangerous practice of using kerosene to start or kindle a fire in a stove or furnace. Kerosene will start a fire quickly, it is true; but you may find yourself with a much bigger fire on your hands than you bargained for.

Among the inflammable liquids that cause explosions are various dry-cleaning fluids. Keep such fluids far away from any open flame or source of heat Open the windows wide when you clean a garment, or, better still, do your dry cleaning out-of-doors. Never smoke or have lighted cigarettes around while the cleaning is going on Keep the container of the fluid tightly sealed when it is not in use. Children should not be permitted to use cleaning fluids

National Board of Fire Underwriters

This home handyman, repairing a toaster, may unwittingly remove safeguards provided by the manufacturer to prevent overheating and shock It is safer to let an expert repair your appliances.

If you polish furniture or apply stain with an oil or wax that is inflammable, be sure that there is no flame near by Use only a little at a time and rub it in well. Any oily cloths that are to be kept even a short time should be stored in tightly covered metal containers away from fire and heat.

A fireplace in a home is a joy for everyone if it is used properly; but it may also present a serious fire hazard To prevent sparks from sputtering kindling or logs from igniting objects within the room, you should set a sturdy wire screen across the opening of the fireplace as soon as a fire is lighted Do not permit children to play near the screen; they may knock it down and forget to replace it. Before you go to bed, be sure that the fire has been put out;

keep the screen in place as an added precaution. Sometimes sparks from a fireplace may issue from the chimney and set fire to the shingles of the roof. A spark arrester — a screen set across the opening of the chimney — will help to prevent such fires. So will the use of shingles made of a non-inflammable material like asbestos.

The Christmas tree is a symbol of good cheer; it is also a real fire hazard. Never set lighted wax candles on the branches; use electric bulbs that have adequate wiring. Do not decorate the tree with objects made of paper, cotton or similar materials; candy canes, oranges, nuts and apples make just as colorful ornaments and they are infinitely safer. Bear in mind, too, that the longer the tree remains in the house, the more it dries out; and the more it dries out, the more of a fire hazard it is.

Smoking has caused many a disastrous fire. The smoker should never put a lighted cigar or cigarette on a table or bureau top. He may be careful to have the lighted end protrude beyond the edge; he may intend to pick up the cigar or cigarette in just a minute or two. But suppose he forgets to do so? Smoking in bed is also dangerous. Many a tragedy has resulted when a smoker dozed off.

American Mutual Liability Insurance Co

If you toss oily or greasy waste rags into a stack of discarded boxes, you are inviting trouble. The rags may ignite spontaneously, the boxes may catch fire and soon your house may be ablaze.

We have already spoken of fires starting from waste materials left about the house — stacks of old paper, oily rags, rubbish and wooden boxes in the attic or basement. Materials like greasy and oily cloths may catch fire even without an external agent, like a match or a spark; they may ignite from spontaneous combustion. Here is what happens. The inflammable materials, the oil or the grease, contained in the rags, gradually undergo oxidation — that is, they gradually combine with the oxygen of the air even at ordinary room temperature. As a result of oxidation heat is released. The oily or greasy cloths retain a good deal of this heat, and the remaining oil or grease combines more readily than before with the oxygen of the air. This raises the temperature still more, and oxidation goes on at a more rapid rate. At last the temperature is so high that the materials burst into flame. Good housekeeping will help to prevent fires of this kind. We should keep attics, basements and closets cleared of any rubbish that might form such a fire trap. We should burn all greasy or oily cloths, and all cloths used to wipe paint from our hands, unless we provide a closed receptacle for them.

Here are a few more suggestions. Use fire-resistant materials as much as possible for curtains, draperies, upholstered furniture and covers for ironing boards. Glass-fiber materials are ideal in this respect. Keep matches in a metal container with a tightly closed top and set it high enough so that the children will not be able to reach it. The metal container will also keep mice and rats from nibbling at the matches and possibly causing them to burst into flame.

Suppose that, in spite of all your precautions, fire should break out. You should always be well prepared for such an emergency. Keep fire escapes clear of obstacles such as flowerpots or boxes. Be sure that every door leading out-of-doors can easily be opened from the inside at all times. If you live in a large house, famil-

iarize yourself with all the exits that could be used when fire breaks out, so that if flames block one exit, you may at once make for another. It might be well to have family drills, so that each person may know what to do and where to go in case of fire.

Automatic sprinkling systems, which release a spray of water when the temperature rises above a certain level, are efficient but are too costly for the average home. On the other hand small fire extinguishers are not expensive and they are effective if you catch a fire in the early stages. When you choose a fire extinguisher, be sure that you will be able to have it recharged in your own town. Have it inspected regularly to see that it is filled and ready for use. If your home has more than one story it would be well to provide extinguishers for each floor.

Falls

A bad spill may cause painful bruises or broken bones; a particularly serious tumble may prove fatal. A number of different conditions and practices may be responsible for falls; we should be on our guard against them all.

Many bad falls take place on staircases. Harmless-looking rugs at the top and bottom of stairs are responsible for many a "tail spin." Either remove such rugs or else anchor them with a non-slip device. Children should be trained never to leave objects on stairs; adults, too, might do well to keep this in mind.

Staircases are doubly perilous in the dark. Install convenient light switches at both the top and the bottom of each stairway in the house, including the basement stairs; outside stairs should also be effectively lighted. As an added safety measure, it would be well to paint the last step in the basement white.

The staircase should be carefully guarded in homes where there are very young children. In such homes, gates at the head and the foot of open stairways are a must; but remember that they give no protection at all unless they are kept closed at all times except when an adult or older child is about to go up or down. Children, even older children, should never be permitted to slide down the banisters.

Those who are having new homes built should keep all these facts in mind. Of course one way of avoiding the problem of stairs is to build a one-story house, without a basement. If stairs are installed, there should be no "winders" or circular stairs. The risers should be not more than seven and a half inches high; six and a half inches would be better. The width of the tread or step plus the nosing or edge should be at least eleven and a half inches. One sturdy handrail or, better still, two should be provided.

A good ladder is an asset; but if it is wobbly, topheavy, worn out or placed unsafely, it is a hazard that requires your prompt attention. Be sure that your ladder can safely support your weight; be sure that you never leave it in a place where somebody can stumble on it. Above all, never use makeshift ladders made up of chairs, boxes or anything else that happens to be near at hand.

The best way to avoid a fall in walking over a slippery floor or sidewalk is to remove its slippery coating. If you spill liquid or drop fat or peelings upon the floor, clean the floor immediately. Ice on steps, porch or walk should be covered with sand, ashes or rock salt as soon as possible.

If you have to grope your way in the darkness in a room, because the switch or pull cord is set far within it, you may run the risk of tripping over a toy wagon or some blocks. Try to place switches near the doors so that you can turn on the light before actually entering the rooms or just as you enter them. In any case, keep passageways clear within the room.

There have been many jokes about the person who slips on a bar of soap in the bathtub and falls with a resounding crash or splash, but that situation is funny only in cartoons. Many a fall will be prevented if the bathtub or shower has a secure grabrail within easy reach of the bather. A rubber mat placed under the shower will also be helpful in preventing a bad fall.

American Mutual Liability Insurance Co.

How not to use a ladder! You should keep both feet on the rungs while working. Never use a shutter or a window sill as an extra rung, broken bones or fatal injury may well result from such carelessness.

Inspect your yard regularly. Holes in the ground should be refilled promptly with dirt. Loose wire and boards bristling with nails should be removed. Garden tools like rakes and hoes should be kept in their proper storage place and not left in the path of the next passer-by, who may be you!

When you have checked all your equipment and surroundings, you must take still other precautions against accident. Try to avoid extreme fatigue. A tired person is particularly likely to fall; if he is not only tired but in a hurry as well, the chances of a fall are even greater. Absentmindedness is another potential cause of injury. Daydreaming is harmless when you are basking in the sun in your backyard; it is downright dangerous when you work on a high perch like a stepladder.

Burns and scalds

Among the most painful of injuries are those caused by burns or scalds. Such injuries may result, of course, when fire breaks out in the house; but they may also come about in many other ways. They may be caused when you upset pots and pans, containing hot liquids, because they have been left too near the edge of a table or because their handles protrude beyond the edge of the kitchen range. The remedy is obvious enough. Set hot coffee pots well back from the edge of the table; turn the handles of saucepans and other containers away from the edge of the stove.

Keep thick pot holders within easy reach near the range and use them in handling hot utensils on the range and in the oven. When broiling meat avoid too hot a flame; you may be spattered with burning fat when you open the oven door. If you use a cook stove, never let it become overheated. Be careful when you carry a pot or pail full of scalding water.

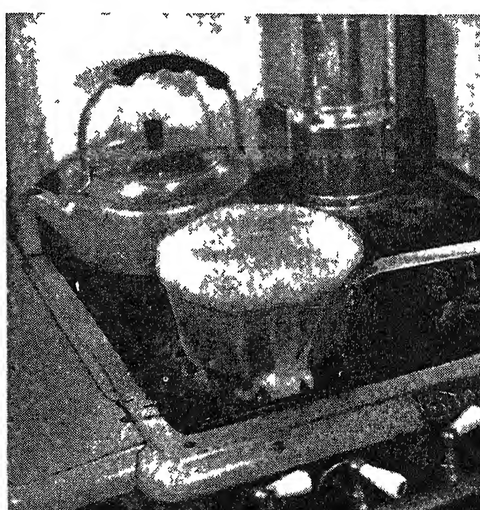
Pressure saucepans and cookers greatly reduce the time necessary for cooking foods, but since they contain live steam under considerable pressure, they may cause face-scarring burns if you open them prematurely. Some pressure pans can not be opened at all until all the pressure has been removed, thus insuring a large degree of safety. The most reliable rule to apply here is to follow the directions given by the manufacturer.

Electric shock

The current that runs through the electric wires in our homes does not exceed 125 volts. Since it takes from 1,800 to 2,000 volts to kill a condemned prisoner in the electric chair, the danger of electrocution in the home may seem very slight. It is true that if the average person comes in contact with the house current he will probably receive a disagreeable shock and no more, *provided that his body is dry.* The reason is that the human body normally has a high degree of resistance to the electric current. However, this degree of resistance depends upon a number of factors. If the skin is dry, the resistance is from five to twenty times as great as when the skin is wet. If a person standing in a bathtub full of water touches a defective electric fixture, he may well receive a fatal shock. Even a comparatively mild shock may prove fatal to a person with a weak heart or in a generally weakened condition We should therefore avoid all contact with the house electric current.

We have already discussed the matter of keeping electrical equipment in good working order. Here are some further suggestions. No wall outlet should be placed within reach of the bathtub or washboard or kitchen sink — the places where water is made available to members of the family. Unfortunately, in some houses that is just where wall outlets are located. In such cases, remember that you should never touch either the outlet or any equipment connected with it with wet hands. Above all, never touch anything connected with the electric current of your house while you are in the bathtub.

Many outlets are only slightly above floor levels, so that childish fingers can probe their dangerous depths with hairpins or similar objects. It would be well to provide all such outlets with guards, which permit access to the socket holes only when a plug is to be inserted.



American Mutual Liability Insurance Co.

Household gas is a dangerous fuel; use it cautiously. Do not allow liquids to boil over; if they put out the flame, gas will flood the room.

If you wish to repair a worn-out electric cord, be sure that the appliance is disconnected. Many a homeowner has absentmindedly snipped a cord above the frayed part without bothering to disconnect it, with most unhappy results. It is best to leave complicated repair jobs to a competent electrician.

Poisons and poisonous gases

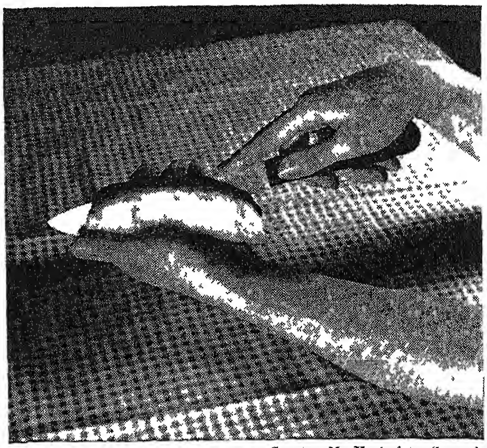
One way of preventing accidents caused by poison would be to keep all poisonous materials out of the house. But poisons like iodine or ammonia or sodium arsenite may serve a useful purpose; they may guard us against infection or cleanse our garments or keep vermin out of the house. They are not the only possible sources of poison; certain medicines or drugs may be most harmful if taken in too large doses.

The important thing is to see to it that no member of the family swallows poisons, either because he mistakes them for something else or else because he is too young to know better. We should clearly label all bottles and other containers of antiseptics, medicines, insecticides and the like and keep them in a cabinet high above the reach of young children. As an added measure of precaution, it would be well to keep the cabinet locked.

It has been suggested that if pins are inserted in the corks of each bottle containing poison, anyone reaching for such a bottle in the dark will be forcibly reminded of its contents. Some people may feel, however, that this is a rather drastic measure, and they will be content with the less painful precautions noted above.

As we have seen, illuminating gas is a serious fire hazard. It is just as dangerous if it is breathed in considerable quantities. A leak in the gas pipe or an open gas cock will flood the house in time, if the windows and doors are closed, with enough gas to cause unconsciousness or death. So when we keep our gas apparatus in good working condition, we are guarding against a double danger.

Even when the gas stove is properly lighted, it can be a source of danger, for the flame uses up oxygen. Every winter



Greater N. Y. Safety Council

This is a very dangerous way to use a knife. Make cutting strokes away from your hand, rather than toward it, whenever it is possible to do so.

we read of people meeting death by asphyxiation because they tried to keep warm by lighting gas ovens and closing all windows. Remember that a kitchen range is *not* a heating unit. If your house is cold, bundle up in warm clothing or get into bed or visit a neighbor.

Poisonous gas fumes are sometimes given off by heating units that have become caked with soot or in which combustion is imperfect. Have your heating unit checked and cleaned by a competent service man at the start of each heating season.

Cuts and scratches

Pins or needles that are left lying on the floor or upon a chair or sofa have resulted in many scratches and infections. The writer recalls a case in which a careless person dropped a needle on a dining-room rug and left it lying there. A young girl, running barefoot over the rug, ran the needle into her foot. The foot became badly infected and required the doctor's care. It is best to do all your sewing in a special room set aside for that purpose. After you have finished sewing, put all your sewing implements — needles, pins, scissors and so on — back where they belong; and do it *at once.*

Knives, forks and other sharp tools misused or used in haste are responsible for many injuries, minor and severe. Sharp

knives must be used carefully and stored safely. When using a knife, make cutting strokes away from your hand, rather than toward it, whenever it is possible to do so. Wash and dry knives separately, and store them in a knife rack out of reach of childish fingers. Children should never be permitted to use knives until they are old enough to handle them safely. Never use the sharp edge of a knife to pry open a jar. Scissors should be handled with care by adults and kept out of reach of young children.

Since so much of our food comes in cans, it is important to be able to open these containers safely. Select a can-opener that leaves no jagged edges to cut the user. An excellent type is the revolving-motion opener, which folds the sharp edges underneath. Avoid haste in opening cans equipped with a flat key for removing a metal band. Turn slowly so as to prevent breaking the band and handle the sharp edges of the band carefully.

Safeguarding young children

We can reason with adults and older children; we can win their co-operation in preventing accidents. But the very young can not co-operate in this way and therefore we should take particular pains to safeguard them.

One of the most dangerous places for little children is the kitchen. They should be kept out of this room as much as possible; if they are permitted to enter it, they should be watched every minute of the time. Needless to say, the mother should keep young children away from hot stoves or cooking ranges, and from all moving kitchen equipment, such as washing machines, clothes wringers, electric mixers and food choppers.

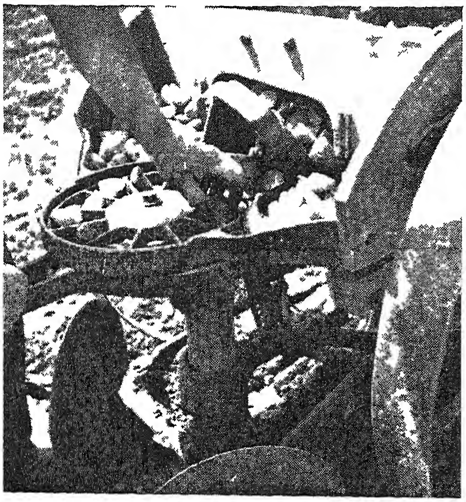
Play pens will protect children from many hazards while the mother is busy. For safe sleep, the baby crib with closely spaced slats will help prevent falls. So will low chairs for young children

Since the serious business of the very young is play, we should be particularly careful about the toys that we put into their hands. Toys should be strongly built, with smooth surfaces and rounded corners. Metal toys should have no sharp point; edges should be rolled. Never give a toy so small that it can be swallowed. Rag dolls or stuffed animals are safe toys, *provided* they are washable and that they do not have eyes made of glass or pins.

Are you appalled by the long list of accidents that can happen to you or to a member of your family? Yet no accident need result in most homes if each member of the family will co-operate in the task of removing every possible hazard. It will be a never ending task but it will be worth all the effort that you put into it.

National Board of Fire Underwriters

Two important safety rules are being violated here. The handle of the coffee percolator should not protrude beyond the edge of the range; the little girl should not be allowed to stay so near it.



Standard Oil Co (N J) Photo by Parks

This ingenious potato planter deposits pieces of potato in the soil at carefully spaced intervals

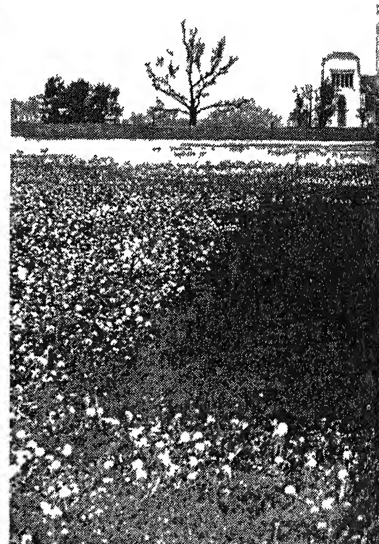
SCIENCE AND AGRICULTURE

The farmer has always been a key figure in the community, for the survival of mankind depends, in great part, upon his efforts Within the past few generations science has come to his aid — and ours, too — and has made it possible for him to increase greatly the productivity of his land and his livestock Scientific methods of conserving the soil have saved countless acres from erosion and have redeemed for agriculture many farmlands that had been abandoned The farmer increases the effectiveness of his efforts with machines like the mower, the reaper, the thresher, the self-binder, the combine, the corn-picker, the cotton-picker and the flame-cultivator He uses electricity to pump water, to run milking machines, milk coolers and cream separators, to dry hay, to grind grain, to cut and store silage and to operate power tools The science of genetics has enabled the farmer to produce hardier and more fertile plants and animals New insecticides, developed in chemical laboratories, have aided him immensely in the unending fight against insect pests The modern science of chemurgy has enabled him to utilize plant products that formerly were considered as wastes

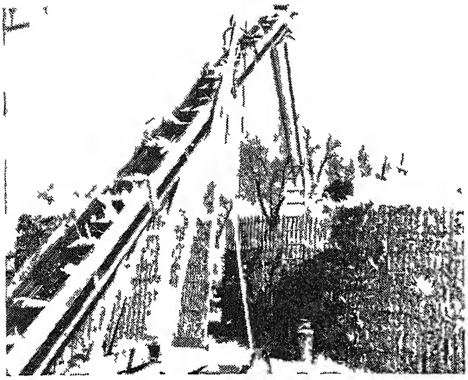
On this page and the one that follows, we show some recent developments that have lightened the farmer's work

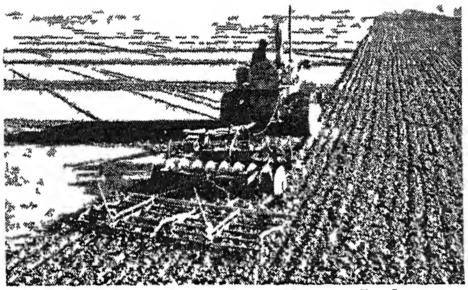
Prime Manufacturing Co

After the electrified fence shown above is installed, cows stay in their own pasture If the animals come in contact with the wire, they receive a shock that is unpleasant but not harmful



The weed killer, 2,4 D will kill most plants, but not grass It was used on part of this field



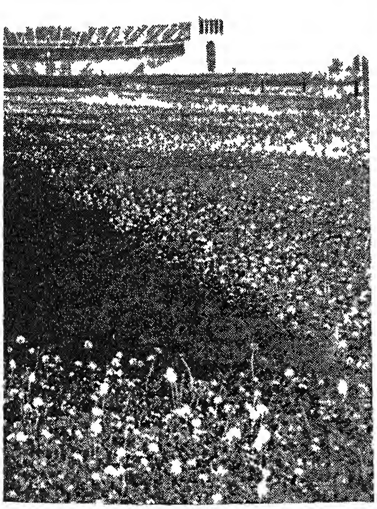


Upper photo U S D A lower photo Caterpillar Tractor Co

Above ears of corn carried upward on an endless belt fall down a chute and into storage on a Minnesota farm Below a Caterpillar Diesel D4 tractor, pulling a disc and two sections of harrow, prepares the ground for the planting of flax

United States Rubber Co

In this plucking machine rubber fingers quickly pluck feathers from a turkey The rubber fingers are mounted on a drum that turns at high speed The bird is first dipped in boiling water, and then held against the fingers for thirty seconds

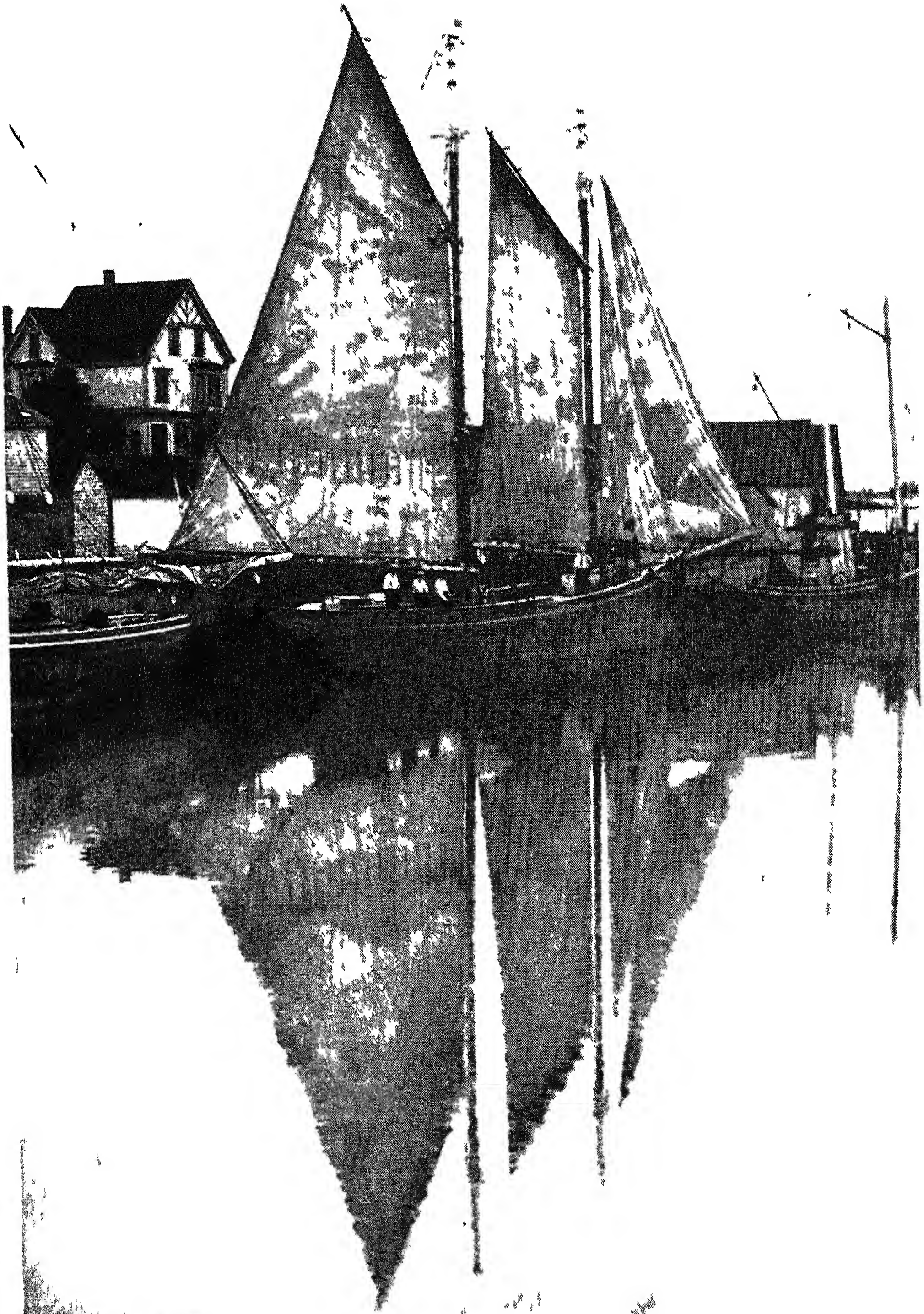


Sherwin Williams Co

(the rectangular area in the foreground) It killed dandelions in this area but left grass intact

Aluminum Co of Canada

The barn, silo and storage sheds shown above are made of aluminum, the light and strong metal that modern metallurgy has made available to mankind for a good many different purposes



Prince Edward Island Travel Bureau

Fishing boats tied up at Murray Harbor, in the small Canadian province of Prince Edward Island.

THE HARVEST OF THE SEA

How the Sea is Made to Give Up Its Fish for One of Man's Favorite Foods

THE DEVELOPMENT OF A PRIMITIVE INDUSTRY

ONE of man's first efforts to satisfy his omnivorous appetite was directed, without doubt, to the catching of fish. Long before he had provided himself with efficient weapons to hunt the wild beasts of the forest, he must have tried to spear or snare the inhabitants of the waters. All primitive peoples had fish spears, hooks and lines, and in some instances very ingenious traps, automatic in action. Civilized man has not only improved on the old methods but he has also invented new ones in keeping with his other great advances in mechanics. The United States Census lists over forty different kinds of apparatus for capturing fish, including many kinds of nets, pots, traps, lines, dredges, harpoons and hooks.

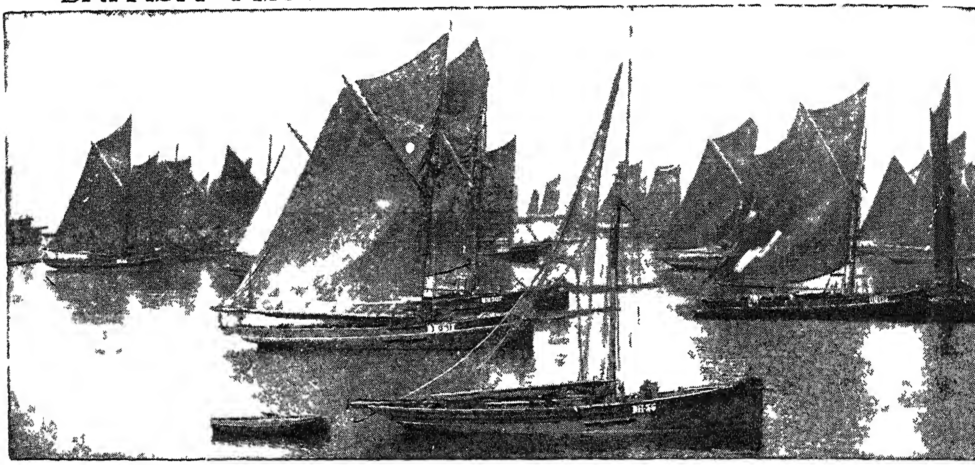
Nature has been marvelously lavish in the number and variety of living things that dwell in the waters, and while only a small part of these is suitable for human consumption, they are all of use in another way, inasmuch as those of less value to us directly furnish food for the edible varieties. In this country alone over one hundred species of fish proper are listed as important elements of our food supply. Fisheries have played an important part in the histories of many nations, both ancient and modern, and are today a vital factor in the life of several European countries. England, Germany, France, Holland, Belgium, Denmark, Norway and Sweden all depend on the sea for a large part of their food supply, and from some of these countries fish is also an important article of export.

While every nation naturally develops boats and apparatus especially fitted to its own waters and the fish found therein, the general methods are about the same the world over so far as fishing on a large scale is concerned. A brief description, therefore, of the fisheries of Great Britain will serve to illustrate what the modern industry is like. No parts of the ocean's waters have been more plentifully supplied with edible fish than those which surround the British Isles. This is particularly true of the North Sea.

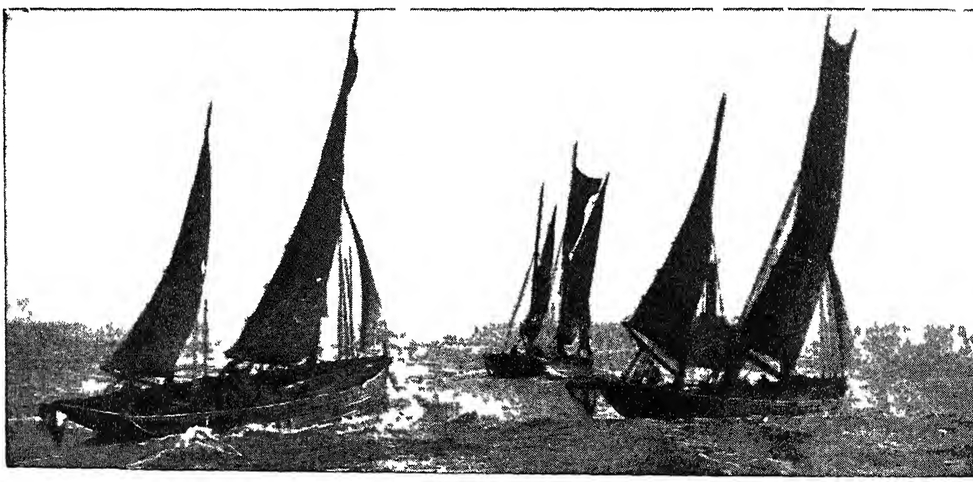
England and Wales have already caught more than 1,000,000 tons of fish in one year. Most of this catch is consumed at home. Some sixty per cent of this great catch are herring, haddock, cod, and plaice (flounder) and sole. The rest consist of other less important varieties. The fisheries are entirely salt-water, and the Englishman, a natural sailor, long ago began to push out farther and farther from shore in his handy little "fishing smack", a vessel well adapted to the work and equipped with the simple lines and nets still common.

The North Sea sailing smacks of the middle of the nineteenth century were stanch, picturesque, and fearlessly handled, but modern conditions of markets and railroads demanded more than they could accomplish. First, steamships — "cutters" — were requisitioned to take the fish from the deep-sea fleet to market. Then steam was used to haul the huge and ever increasing net. Then the steam trawler was evolved. The years that followed saw the development of craft powered by gasoline motors or by Diesel engines. Modern methods of refrigeration and the depletion of the nearer grounds have played an equally important part in widening the sphere of operations.

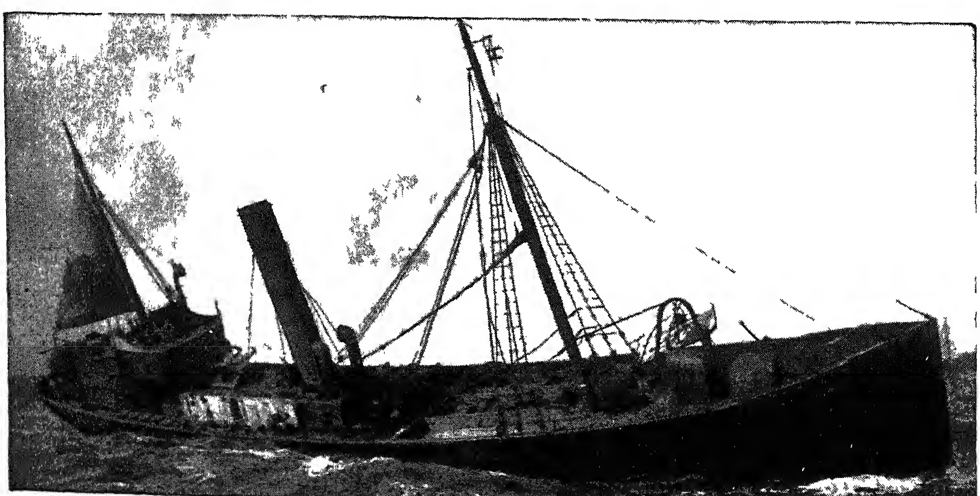
BRITISH FISHING SMACKS AND TRAWLERS



FISHING SMACKS OFF BRIXHAM PIONEER PORT IN THE BRITISH FISHING INDUSTRY

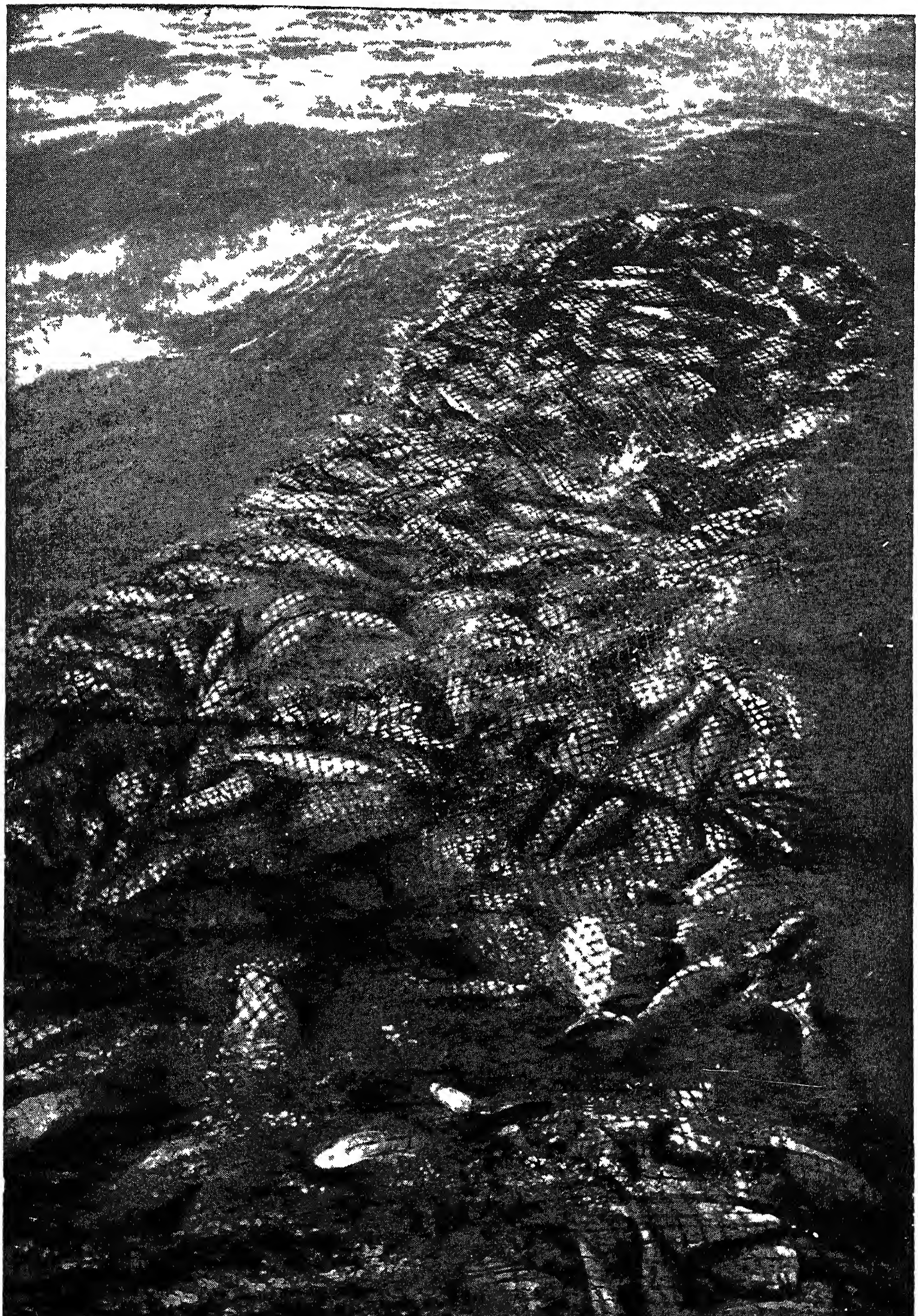


DEEP SEA TRAWLERS BELONGING TO THE LOWESTOFT FLEET



TYPICAL STEAM TRAWLER OF THE NORTH SEA

THE TRAWL-NET BRINGS ITS HARVEST HOME



A TRAWL-NET FULL OF COD, MULLET, SOLE AND OTHER LARGE FISH

Fish caught by the trawl exceed in quantity, variety and value those caught in all other ways. In America the term generally means a long line attached to buoys, with hundreds of shorter lines fastened to it, each with its baited hook. The English trawl is a large net dragged by a moving vessel along the sea-bottom. The net has the shape of a somewhat flattened cone, tapering away from the mouth, its widest part, to the extremity, which is spoken of by fishermen as the "cod end". The trawl has been known from early days, and employed in various parts of the world. There are two types now in general use, distinguished by different methods of keeping open the mouth of the net

The earlier form, and the one now used by practically all the sailing trawlers, is the beam-trawl In this the upper edge of the trawl mouth is attached to a heavy beam, usually of oak, raised from the bottom on a pair of iron "trawl-heads", which somewhat resemble very short sleigh-runners, and act in a similar manner, as the trawl is towed along the sea-bottom. The lower part of the mouth of the net is attached to a thick "ground-rope" or "foot-rope", which is frequently weighted by the addition of pieces of heavy chain, so that it may the more thoroughly drag along the sea-bottom and so secure those members of the flat-fish family that are wont to lie buried in the sand. The length of the beam, and therefore the width of the mouth of the net, as used by the first-class sailing trawlers, or smacks, is usually about forty feet; and the height of the trawl-heads, and hence of the net mouth, is about four feet. Two strong ropes, the "bridles", are shackled to each trawl-head, and these are attached to a further rope, the "warp", which acts as the towing-line. The warp is generally passed over the rail on the port side of the vessel The net is hauled up by means of a capstan, which in former times was worked by hand, but first-class smacks now carry a small donkey engine for the purpose Smaller vessels use correspondingly smaller trawls, the smallest in use being shrimp-trawls of six to eight feet in width.

The most modern form of trawl net is the otter-trawl. The general shape of it is quite similar to the beam-trawl, but the mouth is kept open by two large "boards" which are attached to each side of the net and shackled on to the warps of the towing-gear in such a manner that they "sheer" apart when drawn through the water in a way that is perhaps best described as similar to the flying of a kite. The most obvious advantage of this arrangement over the beam-trawl is in the increased size of net which it renders possible. The width of the older type of trawl is limited to about 40 to 45 feet by the necessity of having a beam that can be carried along the rail of the bulwarks when hauled inboard. Neither is an excessive height of the beam-trawl "heads" practicable. With the otter-trawl,

OTTER-BOARDS ENTERING THE SEA

the size of the net can be much greater, the only consideration being that of the power needed to tow and haul it; and the head-line, instead of being horizontal, extends upward in the form of a bow, and so the net fishes higher in the water than does the beam-trawl. When stowed inboard, the otter-boards are far less cumbersome than the unwieldy beam and "heads", although the net — as used by the steam trawlers of Grimsby, Hull or Fleetwood — may have a spread of head-line as long as 120 feet. This trawl is used nowadays by all steam trawlers, and by a few small sailing smacks, while practically all smacks keep to the more manageable beam-gear.

By far the most important food-fishes caught in the trawl belong to the flat-fish or to the cod family, because of their habit of remaining on the bottom.

A MARVELOUS CATCH AT ONE HAUL

EMPTYING THE NET ABOARD THE TRAWLER, THE "COD END" BEING STILL FULL

About 1880, steam vessels began to be used for beam trawling, and from that time Grimsby and Hull developed with great rapidity. Gradually the steam trawlers, which did such heroic work as mine sweepers during and after World War I, displaced the old smacks from the distant fishing grounds of the North Sea It was the adoption of the otter trawl that was chiefly responsible for this development. With steam trawlers it was possible to increase greatly the size of the net and boards, until they became massive, iron-bound "doors," as they were appropriately named by fishermen. At the present day, sailing trawlers are almost never found as far north as the Dogger Bank They have been replaced by steam trawlers or by the more recently adopted motor ships.

The yield of the North Sea grounds soon became too small to satisfy the more enterprising spirits of Grimsby and Hull With vessels of greater power and capacity and with the increasing use of ice as a refrigerant, the field of trawling operations was greatly extended. The expansion was first to the north, as far as the practically virgin grounds off Iceland, and eastward to the North Cape, on the island of Mageroy, lying off the northern coast of Norway. Today the Atlantic trawl fisheries are of great importance. Off the west coast of Scotland, as far as the distant island of Rockall, where cod, haddock and halibut abound, to the west and southwest of Ireland, in the Bay of Biscay and as far south as the coast of Morocco, British power-driven trawlers may be found towing their gear to a depth that ranges up to two hundred fathoms. Off Portugal, too, a fishery for the ever more valuable sole has been developed

The history of British fisheries reveals the triumph of the power-driven trawler. Still, there is much to be said for the old-fashioned "liner," as those will heartily agree who have tasted fresh, line-caught fish and compared them with trawled specimens of the same species. The huge bag of the trawl sweeps over the bottom of the sea, and "all is fish that comes to the net" — large and small, sickly or sound, fasting or full It is a question of quantity versus quality. In this age, quantity wins out.

National Film Board

This huge catch of salmon is being packed in ice on a barge moored to the pier of a Canadian cannery.

THE GRACEFUL, YACHT-LIKE LINES OF THE GLOUCESTER FISHERMAN

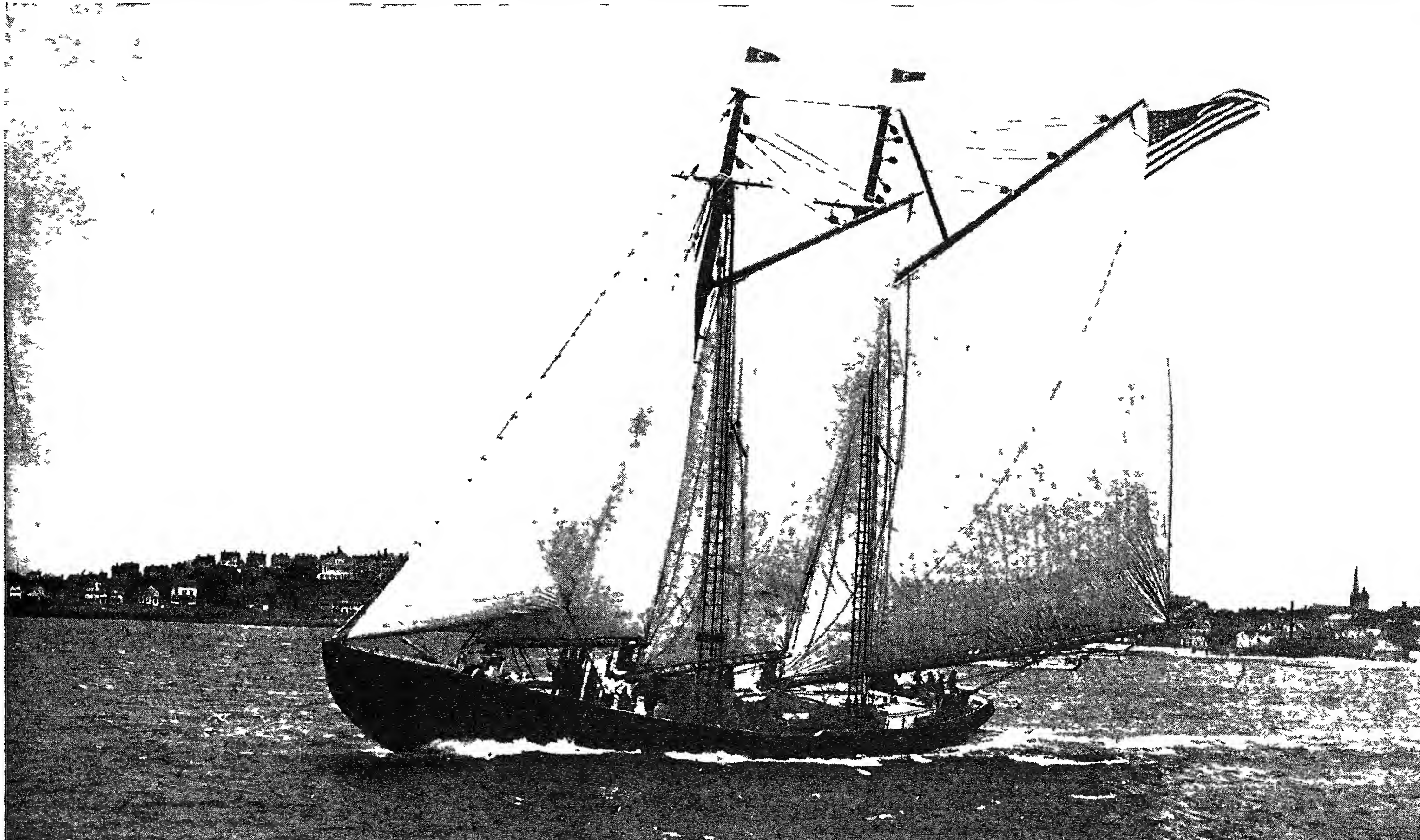


Photo Gloucester Chamber of Commerce

GLOUCESTER FISHING SCHOONER *CATHERINE* OUTWARD BOUND

The beautiful and fast-sailing vessels represent the most advanced stage of commercial sailing craft

The species that may be taken on lines include practically all that may be caught in the trawl A notable exception is the sole, which, from its somewhat special diet of small marine worms, is only exceptionally found on the lines. A certain number of steam liners work the Faroe, Iceland and Rockall grounds for cod, haddock and halibut. The halibut affords them their chief asset, and it is the only important food fish that is caught in greater quantity by liners than by trawlers. These gigantic flatfish are kept alive in "wells," out of which they are commonly hauled by ropes that are passed around the tail.

Among continental nations the French take the first place as fishers. They follow their own methods, with steam trawlers and liners from Boulogne and Fécamp, and sailing vessels from Dunkirk to Paimpol. The sardine fishery is located in the Bay of Biscay and the Mediterranean. The sardine — the young of the pilchard — is caught at sunrise or sunset in a small-meshed drift net, dyed a greenish blue to render it invisible. The sardines are tempted into the net by handfuls of salted cod's roe thrown on the water.

Norway has an energetically conducted fishery, particularly off the Lofoten Islands,

Ewing Galloway

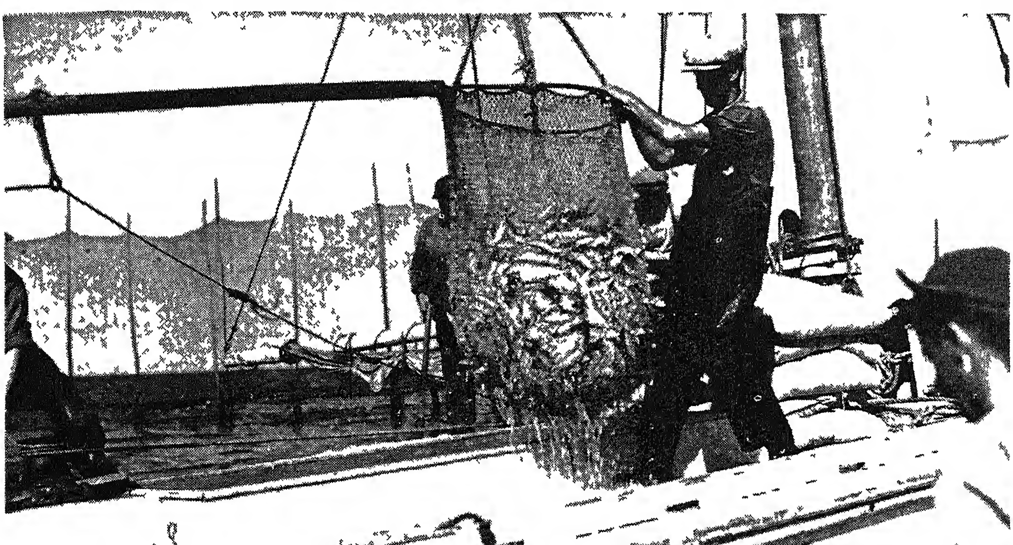
Norwegian fisheries are the largest in Europe. Here Norse fishermen stack salted fish to dry.

and the Government gives intelligent assistance through a study of the breeding and migration of the fish. The fisheries of Sweden are subsidized by the state. Denmark, above all other countries, is the nursery ground of the plaice. The transplantation of plaice to inland salt waters has been successfully carried out. The eel fisheries of Denmark are very valuable, and the Danes stand first as students of the life history of this wonderful fish. The herring fishery of the Dutch employs a considerable number of vessels. The herrings are salted as they are caught instead of being rushed to the nearest available fresh-fish markets.

The objects of the trawl and line fisheries are those species that live and feed on or near the sea bottom. The other important class of fish, known as pelagic fish, includes the herring, pilchard, sprat, anchovy and mackerel. These swift-swimming and relatively small fishes have the convenient habit — from the fisherman's standpoint — of moving at certain times in vast shoals. The nets used for their capture are rectangular pieces of netting of suitable mesh which are suspended perpendicularly in the water. The fish swim into the obstacle, especially in the dark, before seeing it, and are enmeshed by the gills or first dorsal fin.

The total annual catch of fish throughout the world is about 30,000,000,000 pounds. The United States and Alaska contribute something like 5,000,000,000 pounds to this total. In the year 1950, this catch was taken by 170,000 fishermen, who utilized 10,500 vessels of five tons or over, 48,000 motorboats, 34,000 other boats and 1,500 craft for transportation purposes only.

Handling and processing the catch ashore required 110,000 workers in 4,275 plants. Some 300,000 were employed in allied industries — gear manufacture, boatbuilding, fuel, food services and maintenance. The canned fishery products and by-products of the United States and Alaska have sometimes come to about $300,000,000 a year.



New Brunswick Information Bureau

Herring from New Brunswick's fisheries may be consumed as "boneless snacks" in Chicago or Boston.

Few countries have the choice of a larger variety of edible fishes than America. In the North Atlantic, cod, haddock, hake, pollock, halibut, mackerel, bluefish, herring, sea bass, swordfish and others are plentiful. The South Atlantic furnishes mullet, spot, Spanish mackerel and bluefish; the Gulf of Mexico supplies mullet and red snapper, among a host of other fishes. The rivers of the Atlantic coast yield enormous quantities of shad, alewives, smelt, bass and perch. Inland streams and lakes abound in trout, whitefish, herring, pike, perch and a great many others. The waters of the Pacific coast and those of Alaska also support important fisheries; salmon, herring, tuna, halibut, squids, crabs and flounders are caught.

The early settlers on the North Atlantic seaboard naturally brought with them the methods of European fishermen, adapting these methods to their new home. Beginning with shore fisheries, utilizing lines, nets and traps, these pioneers soon began to push out into deeper water as their needs and opportunities developed. The most picturesque chapter, perhaps, in the history of offshore fishing has been furnished by the whaling industry, which for many years had its center in New Bedford, Massachusetts. From this and other New England ports, the stoutly built, though awkward, whaling ships sailed to the antipodes and far to the frozen regions of the north and south in search of whales. The chronicles of these ventures contain numerous stories of hardship and thrilling happenings. America's whaling industry reached its peak in 1846, when 729 vessels were employed; but after that date it steadily declined. The Norwegians hold the first rank in today's whaling industry, which is very efficient. Whaling ships now not only catch whales but also process the great mammals at sea.

Of the many fishes found along the Atlantic seaboard the most numerous by far belong to the herring family, and of this family the menhaden leads easily in point of numbers. This fish, which is known by many and in some instances inappropriate names, abounds from Maine to Florida, swimming in great schools from which they are usually captured by big purse seines operated by two vessels. The menhaden, while of prime importance as a food for other fish, is not particularly valuable as human food, but large quantities are caught and converted into oil and fertilizer. The United States Bureau of Fisheries reports that in one year more than 1,000,000,000 of these fish were taken, and yielded 6,500,000 gallons of oil and 90,000 tons of fertilizer. Yet, it is said that the number of menhaden captured by man for such purposes is insignificant compared to the number devoured by their natural enemies.

Another important member of the herring family is the shad, which appears periodically in great numbers in the rivers of the Atlantic Coast. Probably no food fish is more highly prized than is the shad, particularly those that come from the waters of Chesapeake Bay. The annual catch is valued at over $2,000,000. One of the most important of the shore fisheries in America, as in Europe, is that of the sea-herring. This most valuable fish, the true herring, that has changed the destinies of cities and nations, abounds in the waters of the New England States and Canada, and while the money value of the catch is not so great as that of some other marine products, it has always been, and must always remain a most important industry.

Gill nets, haul seines and purse seines are all used in the herring fisheries in this country, but the characteristic method in the most important fishing regions is the brush weir or trap. This contrivance, which is simply an enlargement of a very ancient device, came into use in this country about 1820 and is now the principal means of catching herring along the coasts of Maine, New Brunswick and Nova Scotia. The weirs are simply enclosures made by driving down stout stakes and interweaving brush between them so as to form a wall through which the fish cannot pass. "Wing leads", or approaches, often guide the fish into the inclosure from which they are prevented from escaping by the closing of the entrance. The weirs are situated in the path the herring habitually travel, and they usually are near the shore or between the shore and an island. The herring are usually taken from the weir by dip nets, though sometimes the receding tide leaves them "high and dry" on the beach. Over $20,000 worth of herring have been captured in one season in a single weir. The herring of the Pacific Coast differs somewhat from that of the Atlantic Coast, but it is a very valuable food fish, and while the Pacific herring fisheries are as yet of minor importance they have great prospective value.

The great fishing centers of the North Atlantic are at Yarmouth in Nova Scotia and at Boston and Gloucester in Massachusetts. Vast quantities of fish are received annually at these ports. Gloucester, indeed, has become synonymous with fish, fish-curing and packing, and the industry at this place has developed a remarkable type of fishing vessel.

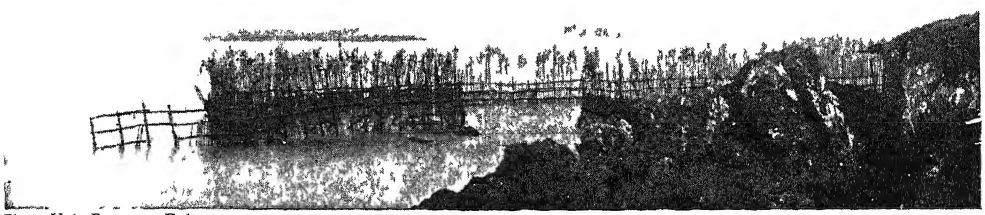


Photo U S Bureau of Fisheries

A BRUSH WEIR ON THE COAST OF MAINE
The opening into the weir is seen in the center.

Since its foundation its fishermen have been ever putting farther to sea, extending their range, till now they fish from the capes of Virginia north to Greenland and Iceland. The need of speed in getting to off-shore fishing grounds, such as the "banks" off Newfoundland, long ago drew the attention of Gloucester boat-builders to the designing of fast-sailing vessels, and a very beautifully modeled, rakish craft has resulted. They are schooner rigged, and carry an immense spread of canvas. The mainmast is stepped almost amidships, and the low freeboard and the fine lines of the hull give them a graceful appearance not found in any other sailing vessel outside of pleasure yachts. In these fleet vessels the fishermen visit the "banks", as the great shallows off the North Atlantic shores are called, in all kinds of weather. When line fishing is the method employed, the crew, groups of four or five in flat-bottomed boats called "dories", spread out around the schooner, returning to the vessel to unload their catch. It is hard work, and hazardous, as not infrequently the dories become separated from the vessel, either by fog or heavy weather, and sometimes lives are thus lost But the work has bred a race of fearless and exceedingly skilful sailors, and it will be a pity, in a way, if the steam trawler supersedes the picturesque sailing craft, as the ugly "tramp" steamer has the graceful American clipper ship, with her towering spars and cloud of billowing canvas. The increasing use of beam and other trawls in the fisheries off the New England coast has already occasioned some alarm on the part of the old-time fisherman.

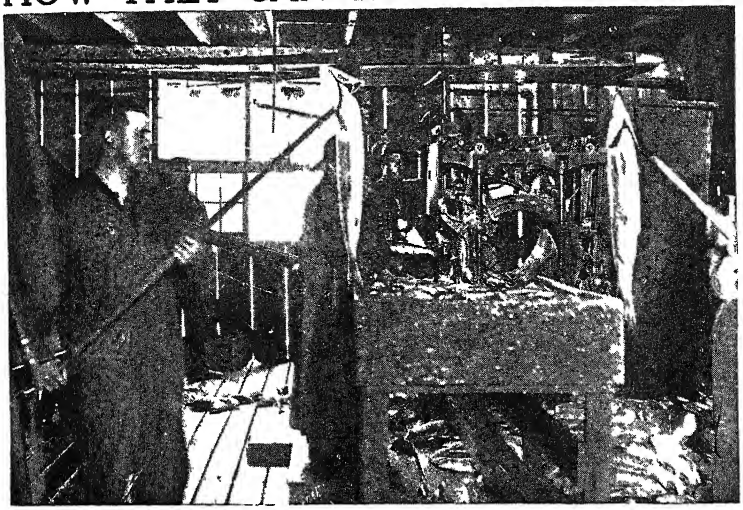
Government regulation is increasingly sought as a protection for the productiveness of these fisheries.

Photo Gloucester Board of Trade

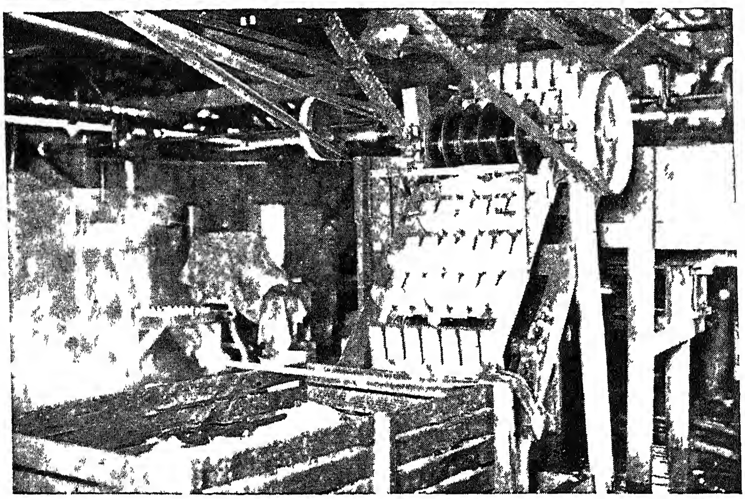
A GLOUCESTER FLAKE YARD

The "flakes" are long tables now usually, for cleanliness' sake, placed on the roofs of the packing houses, and here the last operation of curing is carried on, the wind and the sun thoroughly drying the salted fish

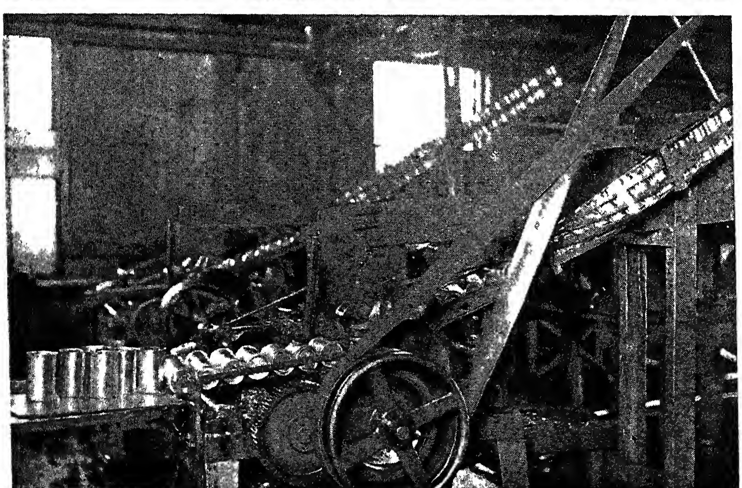
HOW THEY CAN THE SILVER HORDE IN ALASKA



The "Iron Chink", into which the salmon are fed, tail first, at the rate of one a second They come out of the machine with fins, tail and entrails removed, with the inside well washed out and the outside scrubbed clean



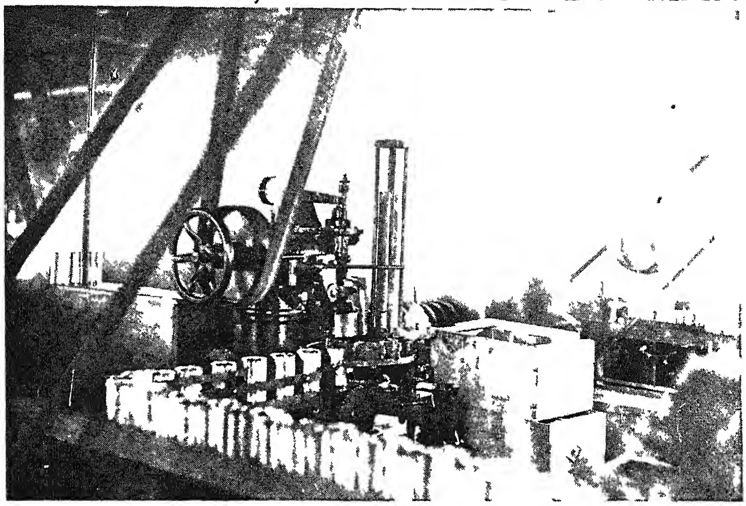
Cutting up machine, in which the salmon are carried automatically against the revolving knives seen at the top of the machine and thereby cut into pieces



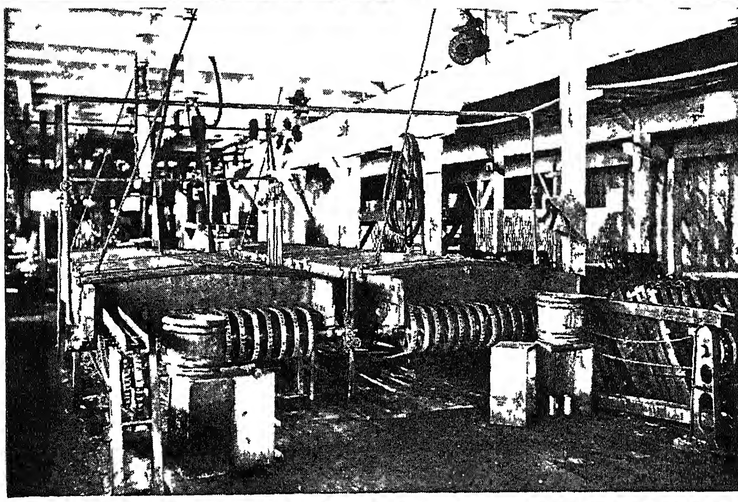
Automatic filling machine which packs the salmon into the can

Photo from *Report of Alaska Investigations*, by Dr. E Lester Jones, U S Bureau of Fisheries

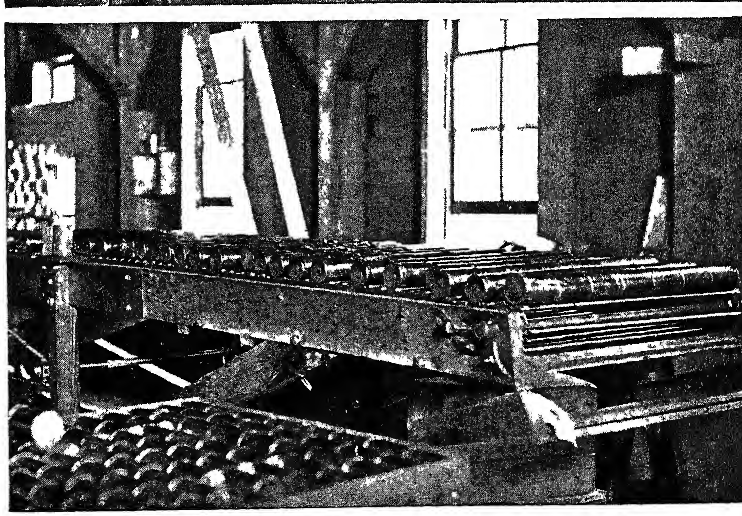
FROM WATER TO CAN, UNTOUCHED BY MAN



In this machine the tops of the cans are automatically put in place



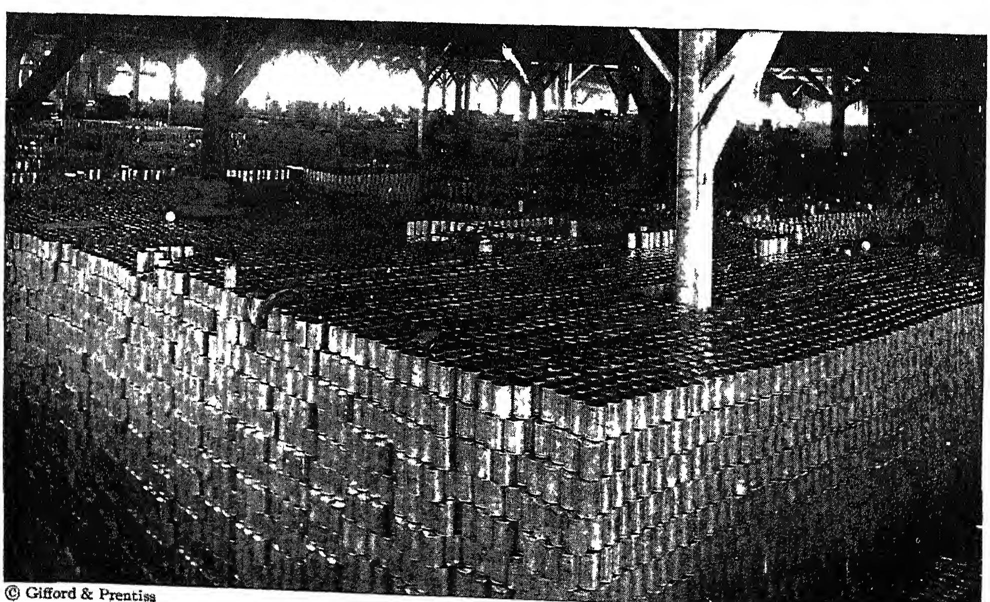
The filled cans are placed in these "steam boxes" in which the air is exhausted from the cans before sealing



Automatic lacquering machine All the cans are automatically dipped in a lacquer to prevent rusting

The waters of the Pacific Coast also furnish a great variety of catch, but by far the most important and interesting phase of the industry is presented by the salmon fisheries of the Columbia River, Puget Sound and Alaska. In British Columbia, too, great salmon fisheries exist, especially at the mouth of the Fraser River. These game fish, of which there are several varieties, live normally in salt water, though little is known of their life and habits in the ocean. Periodically they ascend the rivers to spawn, and in the rivers of the Pacific Coast this migration is participated in by countless numbers. There are several methods employed for catching them, governmental regulation fixing the methods by which and locality where they may be taken, so that enough fish may be sure to escape and ascend to the spawning grounds to insure the future supply. The most important are trap fishing, purse seining, beach seining and gill netting. An interesting adaptation of dip-netting is to be seen on the Columbia River, where "fish wheels" driven by the current and carrying dip nets on their rim are much used. The nets, carried downstream with the revolving wheel, meet the ascending salmon, pick them up, and carry them to the top of the wheel, where they are dumped into a chute. Sometimes the wheels are located on favorably situated rocks near the shore and sometimes they are carried on large movable scows.

Practically the entire salmon catch is canned, and since this must be accomplished quickly, the "run" of salmon lasting only a few weeks, some very remarkable machines have been devised to accomplish this. The most interesting by far is the "iron chink," so-called, "chink" being colloquial for Chinaman, who, formerly the fish-cleaner *par excellence*, was displaced by the machine, which is fed with the newly caught salmon, tail first, at the rate of about one a second. The fish, already beheaded, are carried around a revolving drum, and during the revolution they are cleaned, scrubbed and the fins and tails neatly cut off. Another machine cuts the salmon up, a third packs it into the cans, while a fourth puts on the top. The remaining processes of cooking and sealing are not unlike similar processes in other canning industries.



© Gifford & Prentiss

A MILLION AND A HALF CANS OF SALMON

Interior of a cannery storeroom showing 1,500,000 one-pound cans of salmon ready for shipment.

LISTER AND MODERN SURGERY

The Wonderful Cures now Made Possible by Listerism with Little Pain or Danger

LESSONS OF LIFE OF MODERN WARFARE

IF for nothing else, the first half of the nineteenth century would be noted because man had largely achieved the conquest of pain Thereafter the surgeon was not so pressed for time, and could be more secure; operations formerly impossible could be attempted; patients formerly too fearful could submit to the knife. But if we attempt to estimate the value of anæsthesia in terms of human life as against that of other species, we find it disappointing. The surgeon's patients still died in large numbers; surgery was still a desperate remedy for desperate diseases. The poor fellow with a crushed leg who was carried into the hospital from the railroad wreck could have the leg removed painlessly, and then, a little later, have a second amputation performed higher up, also painlessly, but too often he would die. Something was at work for which anæsthesia was irrelevant. It made operations vastly more possible, and we could say that an operation had been "successfully performed", but the results were still deplorable. One in three was the death-rate after major operations.

In the 'fifties and 'sixties these matters came to be considered by a young surgeon with a brain as well as hands, named Joseph Lister. The surgeon's enemy was *inflammation.* Instead of healing "by first intention", as a tiny cut upon the finger will usually do, wounds became inflamed; and somehow this inflammation affected the whole vigor of the patient, so that often he died. The classical symptoms of inflammation are *rubor*, *calor*, *tumor* and *dolor* — redness, heat, swelling and pain. Lister devoted himself to the study of these symptoms. No one knew their cause, but they suggested a kind of chemical process in the inflamed tissues — as if a sort of slow combustion were going on. Now, combustion is fed by the oxygen of the air. Hence a reasonable suggestion was to try to keep the air away from wounds, in order that they might not become inflamed. Many devices were employed to this end — uselessly. The air had just the same relation to surgical inflammation as the "malaria" of the night and the swamps has to infection by the malarial mosquito. Then there came the great demonstrations of the French chemist, Louis Pasteur. Even though it is our purpose here to pay honor to the great Englishman, Lister, of whom it has been said that his discoveries have saved more lives every year than Napoleon took in all his wars, we must not forget the part which Pasteur played in making this possible. The rare merit of Lister was that he had the brains and the courage to become the foremost of Pasteur's pupils.

Pasteur found that microbes could cause processes of fermentation, including the production of heat and of swelling, in various fluids and mixtures. If, then, exclusion of the air was unavailing to prevent surgical inflammation, with its similar features, perhaps exclusion of microbes, or the killing of them, might have the desired effect. So Lister argued. Pasteur himself argued in the same way, and used to "sterilize", as we now say, his needles and instruments by means of a flame, for his experiments upon animals, just as the surgeon does today when operating on men or animals.

The story of Lister's experimental advance towards antiseptic surgery

But Louis Pasteur did not practice human surgery, and had his own work to do. Lister decided that he must obtain some compound which would arrest *sepsis*, or putrefaction, as it occurs in inflamed tissues; and when he sought chemical help for the purpose he was offered, at the very first, the compound called phenol or carbolic acid, not yet surpassed for most purposes. As this substance opposed sepsis, Lister called it an antiseptic, and his use of it, for surgical purposes, *antiseptic surgery*.

At this time Lister occupied a chair of surgery in Glasgow, and there his first experiments were made. The obvious opportunity for them was in such cases of compound fracture as we have already quoted for purposes of illustration. They commonly involved sepsis. The mark of a compound fracture is that the injury involves a channel from the surface of the broken skin right down to the broken bone. Thus the inflammatory, and soon septic, process appeared in the bone itself, and rapidly spread upwards Often the surgeon, after repeated amputation, failed to arrest it. Perhaps carbolic acid would help him. While performing his amputation (but nowadays he often does better than amputate at all), let him freely use carbolic acid; let the stump of the sawn surface of the bone be so treated also; and if microbes are really the cause of sepsis, and the carbolic acid kills them, the septic process should cease. And so it happened. Lister's earliest series of results were the best that had ever been obtained in human history.

He was appointed professor of clinical surgery in Edinburgh, and there he worked out in detail the principles of antiseptic surgery, greatly aided by his right-hand man, Professor John Chiene. Lister was very thorough in his methods. Little was then known about the behavior and *habitat* of the microbes of inflammation and putrefaction. They were supposed to be omnipresent, which they are not, although it is a very good rule to assume that they are.

Lister told his pupils to act as if every surface of every object, without exception, were covered with "wet green paint" Nothing was to be touched, for infection was possibly anywhere. It was supposed to be in the air, which was figured as full of floating microbes of putrefaction. Lister therefore invented a carbolic acid spray, which injected a fine shower of the antiseptic fluid into the air above the patient and all over everything concerned.

Soon the spray was abandoned, and the results were just as good, or better. Lister meant to make no mistake about his antiseptic measures, but soon he found that not only the spray, but also the great strength of his solutions, was superfluous. Weaker solutions possessed the same almost magic power, and the results became better still The reason is simple enough Carbolic acid is a poison to every form of life, a "protoplasmic poison". It not only kills microbes, but also devitalizes the cells of the tissues which the microbes are attacking. Further, it is to some extent and in certain conditions absorbed into the patient's blood, and there acts as a poison. Fatal cases of carbolic acid poisoning have thus been recorded in the past. Hence weaker solutions, provided they were strong enough, provided stronger arguments, because they produced better results.

The controversy on cleanliness between Lister and Robert Lawson Tait

Lister had some important critics, notably the Birmingham gynæcologist, Robert Lawson Tait, who obtained very good results in many serious cases of certain kinds without the use of antiseptics, but with abundant washing and what may be called domestic cleanliness. These were cases where no microbes were present in the first place — cases of what surgeons call "unbroken skin" — and Tait's results, which could never have been obtained in, say, dirty compound fractures, were very significant indeed. He and his followers denounced the microbe theory altogether, and the opponents of vivisection — without which Pasteur could not have made his discoveries — supported Tait against Lister.

A FAMOUS MEDICAL PIONEER

Brown Brothers

Lord Lister (Joseph Lister), the great English surgeon who founded modern antiseptic surgery.

The real meaning of the facts was not long in doubt, as Lister proved. Where no septic microbes are, and where none are introduced, no antiseptics are necessary, for there is nothing to kill, no work for them to do; and as they tend to weaken the powers of the patient's tissues, they are better absent altogether.

The transference of antiseptic treatment from the patient to the surgeon

Hence, Lister developed an antiseptic surgery, for cases of "unbroken skin", to which he gave the name of "aseptic surgery" — that is, surgery without sepsis altogether. The case is surgically clean, or aseptic, at starting, as when the surgeon breaks rickety bones in order to set them straight, and so cure a bad case of knock-knees. To treat the broken bones with carbolic acid in such a case would simply be to injure them and retard the new union of the bones, provided that the surgeon has never introduced any microbes where none were when he began. He therefore performs an aseptic operation, the point of which is that, while antiseptics are freely employed for his own fingers, for his instruments, for the clothes he wears, and while the skin of the patient is treated with them for many hours before the operation, so as to sterilize it, at the operation itself the antiseptic is washed away, the surgeon's fingers and instruments are all rinsed in boiled water, and thus no particle of any antiseptic comes in contact with the tissues of the patient. In consequence, they heal more rapidly, painlessly and perfectly than under any other conditions.

The fierce opposition to Listerian methods from anti-vivisectionists

No distinction in principle exists between the two methods, and only this one small, but useful, distinction in detail. Lord Lister has, however, been repeatedly attacked, in the interests of anti-vivisectionists, as having, in fact, abandoned as useless the theories which were based by him on Pasteur's experiments, and as having covered up his abandonment of those theories, and his discovery of their falsity, by inventing an "aseptic" system, which is merely the old practice of cleanliness under a new name This allegation against Lister is without a vestige of warrant or excuse. The facts, as they may be verified in any hospital in the world, or any day and at almost any hour, are as we have stated them. Besides being a great surgeon Lord Lister was a man of the most stainless honor; and if his theories had been found false — as, fortunately for mankind, they were not — he would have surely acknowledged his error. On the contrary, every month of every year, from 1868, which marks the introduction of carbolic acid into surgery, up to the present day, has witnessed increasing justification for a method which has, during the same period, steadily advanced in perfection of detail, but in nothing else.

The abolition of inflammation as an after-effect of surgery

Lister's establishment of the antiseptic principle, during his years in Edinburgh, at once transformed the nature of surgery He introduced the catgut ligature, in place of silk ligatures, and could completely close his wounds at the end of an operation, in many cases; for after a little while, when the vessels tied with catgut had closed by natural processes, the catgut itself, being an animal tissue, was absorbed by the animal body in which it found itself, and so there was nothing left to come away after the operation was performed. In Denmark and in France Listerian methods were quickly adopted with success; and at last the surgeons of London began to accept it. The essence of it was that inflammation practically vanished from surgical practice.

The four classical symptoms of inflammation were all due to a struggle for existence, waged in the patient's tissues, between them and microbes. That is the meaning of inflammation, in biological language. The particular kinds of microbes involved belong to the round type, called "cocci", and the most important are those which grow in chains, hence called *streptococci*, and which grow in clusters like grapes, and are therefore called *staphylococci*.

Only too frequently, when these organisms have established themselves locally, they spread throughout the body, and we have the various forms of so-called "blood-poisoning" named "pyæmia" and "septicæmia", diseases where, as the names suggest, the very blood seems to suppurate and putrefy.

What happens in the case of injury from a rusty nail

When we hear that a man scratched himself with a rusty nail, and contracted blood-poisoning, we should know that rust is itself an excellent blood tonic, which could do nothing but good; in fact, people with plenty of "rust" in the blood are those who are least easily poisoned, by rusty nails or otherwise. But some of the cocci we have named have invaded the wound, have there multiplied, and blood-poisoning, by them and their products, and not by the incidental rust, is the result.

Blood-poisoning, the sequel to local inflammation, was the bane of surgery. But Lister stopped all that. The battlefield and the military hospital are perhaps the first places where Listerian surgery, antiseptic rather than aseptic, may be expected to benefit mankind. Lister introduced carbolic acid in 1868, just in time for the Franco-Prussian campaign of 1870–71. But military authorities move slowly; and though Pasteur was a Frenchman, and antiseptic surgery is simply the application of Pasteur's essential discovery that microbes cause disease, neither the French nor the scientific Germans used carbolic acid in that war.

Chloroform, mercifully, was there, but chloroform had had nearly a quarter of a century in which to make its name heard in War Departments. Some thirty years after the introduction of carbolic acid, the Boer War began, and in that unhappy and tragic business carbolic acid played a part. Professor Chiene, Lister's "right-hand man" in the pioneer years in Edinburgh, went to South Africa, and did his best, like many other Listerians. But the conditions were impossibly bad. None of those in authority, whether at home or in South Africa, had any real belief in science. The most elementary ideas, long established by Pasteur and Lister, were ignored. Camps were pitched on typhoidal drainage, the men drank indescribable water, the supply of surgical necessaries was pitifully inadequate; and the great principle against which the representatives of science and the champions of life had to contend in that deadly campaign was the dictum of an illustrious soldier (not himself engaged in South Africa) that "Medical advice is a very good thing — when it is asked for".

The failure of England and success of Japan in adapting surgery to warfare

How different the history of that campaign would have been, with the principles of Pasteur and Lister enforced, we can scarcely imagine. More deaths and invalidism were due to neglect of them than to Boer bullets Though Lister was an Englishman, the English did not do so very much better than the countrymen of Pasteur thirty years before.

Then came the Russo-Japanese War, and a very different story. So far as the Europeans were concerned, the science of Europe might not have existed. There were plenty of *ikons* for the sick, but none of that more profound religious worship which we see in the practice of science for their healing. The "yellow monkeys", as Pasteur's fellow-countrymen called the Japanese, had the monopoly of Pasteur's principles, and they bettered all their instruction.

The war resolved itself into a question of man-power; and it came to an end when Japan's resources of men were all but depleted. But those resources had been maintained by unprecedented means, and with unprecedented success. Never in the records of war was there so little typhoid, so little dysentery, such a small proportion of deaths from wounds, as on the Japanese side. The sheerly surgical — *i.e.*, cheirurgical — "hand-workical" — qualities of the Japanese may be guessed from their skill in artistic technique. But this was not the key to the Japanese records. They succeeded because they *really believed* in what they had learned from Western science.

The Japanese use of sterilized underclothing in battle

Now here, as elsewhere in scientific practice, it is the details that make the difference. A surgeon's Listerian theory may be sound, but if he wears a beard, or touches his cheek with his finger while operating, his practice may be a disastrous failure Where we are dealing with microscopic, almost ubiquitous enemies, a slapdash antisepsis is not good enough. The Japanese were thorough, as a single illustration will show. A few years earlier their soldiers and sailors had fought in medieval or barbaric armor, but now, before a naval engagement, the sailors were compelled to take carbolic baths and to don sterilized underclothing; so that they stood up to the Russian guns in the full modern panoply of a "boiled" vest and a "carbolized" skin.

Why more wounded now recover in war than ever before

Modern projectiles, be it observed, are sterile. The temperature at which they are propelled, their rapid flight, and the atmospheric friction guarantee that. If they do not touch a vital spot — and only a small part of the body is vital in that sense — they can kill only by inducing inflammation; and the only source of such inflammation must be microbes in the skin or clothing of the patient, part of which is often carried into the wound. But the Japanese who prepared themselves on Listerian lines were protected; the operations performed on them by the Russian projectiles were modern aseptic operations, of the very newest kind, and the rates of death and injury corresponded. Never before in the history of war did such a large proportion of the wounded return to the fighting ranks and in the late Great War antiseptic surgery and antiseptic treatments rose to still greater heights.

Achievements of antiseptic treatment in cases of accident in civil life

The achievements of Listerism under the more favorable conditions of civil life must briefly be indicated. They depend primarily upon the provision of suitable places, such as no private house is equipped with. Not many years ago, operating rooms were built to accommodate many spectators. Nowadays they are relatively small, with polished tiles, equipped with every necessity, including such *minutiæ* as pedals to turn the water-taps, so that the surgeons do not need to contaminate their fingers; but the regulations are as important as the fittings. The inspecting visitor must don white canvas slippers, provided for the purpose, before he touches the floor, for this, like a Mohammedan mosque, is holy ground, sacred to the service of Life, and there must enter nothing that "defileth".

The precautions taken to assure perfect cleanliness in operating rooms

That, however, is only when the operating rooms are not being used. During operations the spectators, for whom accommodation is provided, must enter by a special door, like visitors to Congress; nor are they allowed on the "floor of the House". You may go to the United States Capitol from anywhere, however — why not, indeed? — but no one may come to these operating amphitheaters from the dissecting-room, the post-mortem room or infectious wards.

The patient and the surgeons and nurses who are to serve him enter by another door, at the other side of the operating room. There is an anteroom where the anæsthetic can be given — a humane arrangement, which averts nervousness in many cases. The air which enters the modern operating room is driven in by the *plenum* system, having first been filtered by passage through a curtain of cocoanut fiber, down which water streams, and its temperature is regulated and kept constant. Patients under an anæsthetic, like persons under alcohol, are liable to catch cold. Finally, we may observe that the current of air is so directed that it reaches the patient first, and then passes from him past the spectators and away. They therefore may possibly receive anything he has to offer them, but nothing they bring in with them can very well reach him.

Note, further, that there is a bacteriological laboratory in the hospital, associated with these operating rooms. The surgeons and their patients are largely at the mercy of the official whose business it is to sterilize everything concerned with the operation — the instruments, the water, the swabs, the aprons, blouses and caps used by the surgeons and their assistants. Where asepsis is aimed at, technique must be perfect, for there is not a free flow of carbolic or bichloride of mercury solution to destroy any microbes which might perchance have reached the patient's wound. Therefore, whenever he will, the surgeon will send say an instrument or a swab down to the laboratory to see whether it is really sterile, as it should be, or whether living microbes can be cultivated from it. Not only so, but he must check the elaborate methods which he employs for sterilizing the skin of the patient and his own fingers. How good the modern methods are, with their sequence of nail-brush, and green soap, and alcohol to melt away the fat, permanganate and iodine solutions, etc., we can guess when we look at the records, and find that, say, for a year at a time, not once have any living microbes been obtainable from the skin of either patients or surgeons after such methods have been employed.

Under such conditions it becomes possible for the surgeon to go where he pleases. Operative technique and procedure soon advanced beyond lowering the death-rate after amputation for compound fracture. Nowadays, the fracture may, indeed, be so well cleansed with antiseptics, the patient being anæsthetized while the task is thoroughly done, that the limb is saved as well as the life. Abdominal operations are now accomplished with success. It is estimated that at least two hundred thousand operations are performed for appendicitis in this country alone every year. Formerly, the inflammation continued to spread, and the patient died of what was called, and was, peritonitis, but its origin was in the appendix, which the surgeon can now reach and deal with. As for multiple fractures, instances have been reported where four were *made* by the surgeon at one operation, one above and one below each knee; and when the bones had healed in the new position which the surgeon imposed upon them, the patient's knock-knees had vanished, and he was some inches taller. For those who know what such setting would have involved, with the careless methods of old-time surgery, this particular operation is as eloquent as any in teaching what Listerism means.

Courtesy U. S. Army Signal Corps

AMERICAN ARMY SURGEONS AT WORK

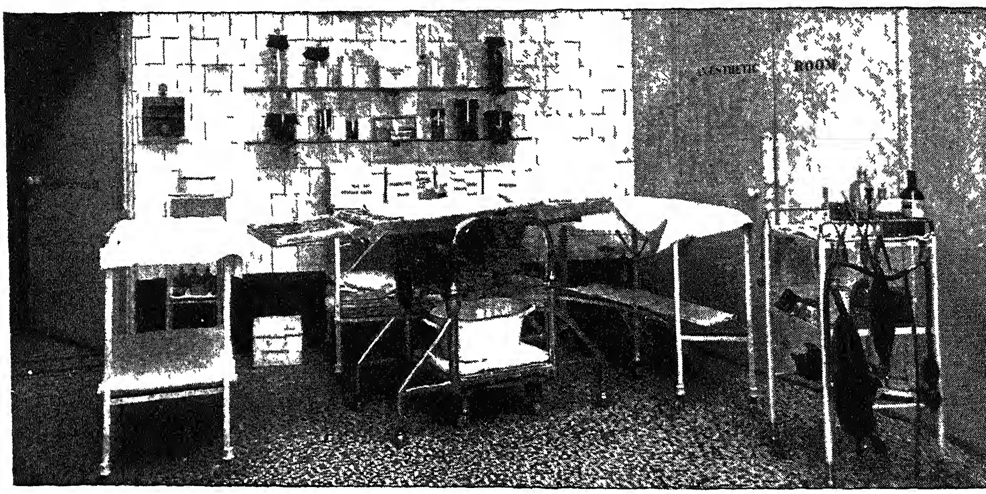
This shows skilled surgeons applying a cast on the leg of a soldier with a deep wound in his thigh, caused by a shell fragment. An evacuation hospital of the U. S. Army near Riardo, Italy, in World War II.

The surgery of the heart is one of the triumphant advances of recent years. A case was recorded in Berlin, not long ago, when an accident caused a *perforating* wound through the wall of the heart, but the surgeons were able to sew it up in time, and the patient recovered — the first man that ever lived to tell such a tale. Sir Lauder Brunton, the distinguished physician, has lately speculated as to the possibility of getting the surgeon to insert a fine knife into the heart and slit open the contracted valve which is responsible for certain forms of heart disease. This has only very recently been successfully performed. It is better to use the antitoxins for the rheumatic and other microbes before they have set up the inflammatory process that contracts the valves; but the

fact that it has been suggested by a famous student of the heart is another measure of the possibilities of modern Listerism.

More remarkable, and of a vastly greater daily value, is the modern surgery of the brain. This, of course, involves the perforation of the patient's skull, but that is no matter nowadays, when the surgeon is sure of his aseptic technique. Thereafter the surgeon may deal with tumors, tuberculous abscesses, bullets, portions of bone carried into the brain from a previous compound fracture and many other conditions Attempts have even been made to "minister to a mind diseased", as, for instance, in cases of microcephalous idiocy, where it was thought that the small development of the brain depended upon the premature arrest of the growth of the skull, and where, on that view, attempts have been made to deal with the skull, so that the brain might have room to grow. We are now assured, however, that the brain condition comes first in these cases: its failure to grow further leads the skull to close, for there is no reason why it should longer remain open, and thus operations on the skull in such cases are of no use. Other cases are recorded where surgical operations have relieved certain forms of insanity, but these are exceptional and dubious.

The pioneer and acknowledged master of brain surgery was Sir Victor Horsley, whose initial researches upon the functions of various parts of the brain in the lower animals led the way to his work upon the human brain in states of disease It is particularly to be noted that Listerism has made surgery, humanly speaking, safe. Further, by preventing inflammation, it has averted the pain which used to follow operations, and for which the beneficent discovery of surgical anæsthesia was of no avail It follows that operations, even upon the brain, need by no means be confined to cases where life is in danger.



WHERE CLEANLINESS IS LIFE — AN OPERATING THEATER, SHOWING THE OPERATING TABLE AND THE DOOR OF THE ROOM FOR ADMINISTERING ANÆSTHETICS

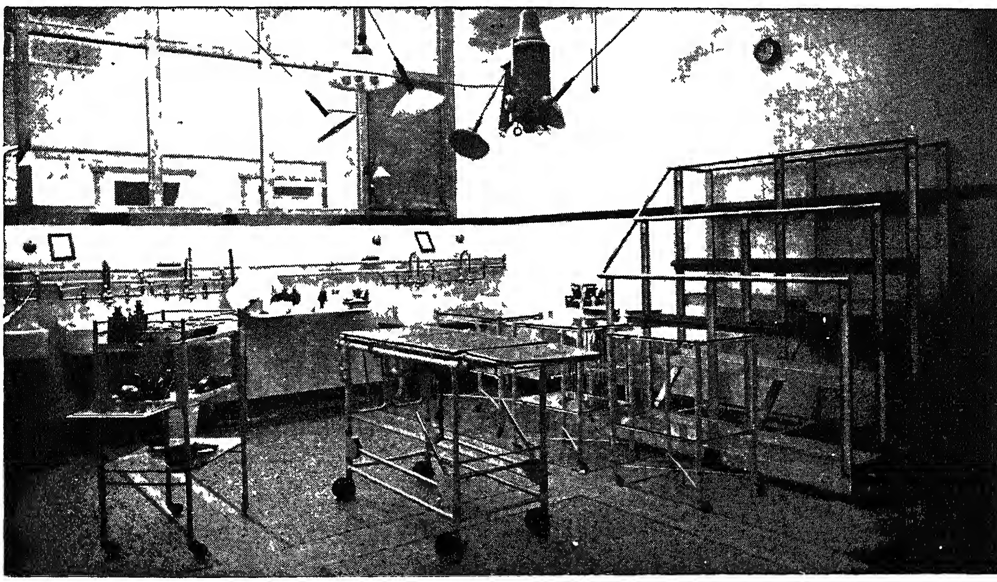
Perhaps Horsley's most remarkable achievement was the surgical relief of cases of extreme facial neuralgia. In elderly people especially, neuralgia, having its seat in the trigeminal or fifth cranial nerve of one side or other, may become so intolerable that life becomes not worth living, and the patient's plight is too miserable for description. In these cases all medical or medicinal measures are often unavailing. Portions of the affected nerve may be reached by surgical procedure, and divided, sometimes to the partial relief of the patient. But it appears that in such cases the seat of the mischief is higher up, in the Gasserian ganglion, or collection of motor and sensory nerve-cells, which is practically part of the brain, and lies under cover of a

lobe of the brain within the skull. The operation has therefore been successfully devised of opening the skull, turning aside the intervening portion of brain, and excising only the sensory part of this ganglion The motor part must not be disturbed as the patient would then be unable to use his jaws The difficulty of this operation is obviously great, but its success is patent. There is one case on record of an octogenarian, who, notwithstanding his great age, bore the operation splendidly, without any evidence of shock, and whose age showed that Listerian surgery, especially where the aseptic technique is applicable, involves extraordinarily little strain upon the vital resources of the patient *No poisoning is involved*, and there lies the whole secret of its success.

The principles which apply to the largest proceedings apply to the smallest. The causes which lead to the extraction of teeth, for instance, are essentially microbic. There may be an infection of the pulp of the tooth, a "pulpitis", as dentists call it. For this the old remedy was extraction alone. But the modern dentist can attack this problem, just as the modern surgeon would a similar inflammation in the marrow of a bone. The pulp can be reached, cleaned out and drained and an antiseptic dressing applied. Then the whole cavity may be filled, and the tooth saved.

Listerian dentistry, like Listerian surgery in general, is thus, like all other valuable things and people, at once conservative and radical If it is valuable to the dentist, it is more so to the oculist Inflammation is a desperately serious matter in the eye, and may utterly ruin the sight forever in a few hours, to say nothing of the extreme liability of the other eye to go the way of the first But now the ophthalmic surgeon can perform the most delicate operations without fear, provided that his patient will take reasonable precautions to prevent infection afterwards

The surgery of the nose and throat has benefited in just the same way. A certain percentage of people, for instance, have what is called a deflected nasal septum; the bony and cartilaginous partition or septum between the two sides of the nose is deflected, so that microbes are apt to lodge in the nose; there is great liability to colds, and in time the voice and bronchial tubes are secondarily affected No satisfactory treatment for this condition existed until a few years ago, when a Viennese surgeon invented a bold but effective operation The nose is painted with cocaine and adrenalin, the surgeon



AN OPERATING ROOM, SHOWING THE STUDENTS' GALLERY, AND THE ELABORATE ARRANGEMENTS FOR SECURING PERFECT ASEPTIC CONDITIONS

makes a flap of the mucous lining of the nose, and removes the entire septum bodily, or rather in pieces of cartilage and bone, with the aid of knife, chisel and hammer. The flap of mucous membrane is then laid down and held with a single stitch, and the patient has a merely membranous partition to the nose for the rest of his days. The benefits of this operation have to be experienced to be realized. Of course, such an operation, with its chiselling of bony structures right up to the base of the brain, would be unthinkable without the protection afforded by aseptic precautions.

The use of aseptic precautions in removing superficial blemishes

All sorts of minor possibilities need barely be mentioned. Skin-grafting becomes possible, and is, indeed, not a minor possibility in cases of extensive burning. The whole of the skin of the back has thus been replaced, after a long time and much trouble, in a case where a burn had destroyed it. Hence we may pass to merely "cosmetic surgery", the grafting of ears and noses, etc. Much may nowadays be done, under aseptic precautions, for the removal of facial and other blemishes, nor need the surgeon regard such procedures as beneath his dignity. They may make all the difference to a life's happiness; and if they are left to those who have no knowledge of antisepsis, inflammation and worse is apt to follow attempts to remove or cauterize moles, warts, etc.

The natural antiseptic agents in the body revealed by Metchnikoff

The great work done at the Pasteur Institute by Metchnikoff and others has shown, since the introduction of antiseptics, that the body contains its own natural antiseptic agents; above all, the white blood-cells, or "phagocytes", as Metchnikoff calls them, and the ferments which these "eating cells" contain. The study of the blood thus becomes a matter of the first importance for the surgeon. For instance, in appendicitis, the surgeon may hope that no suppuration will occur, and that he will not need to interfere until the attack has subsided, and the appendix may be removed conveniently and safely, with the patient in good condition and well prepared. But he must make periodic and perhaps four-hourly counts of the cell-content of the blood, for he knows that, if the number of phagocytes rises markedly, this is the body's response to commencing suppuration, and he must interfere at once, lest the pus infect the peritoneum and kill the patient.

Similarly a case is reported where a surgeon explored a small boy's thigh, where pain was complained of, on the ground that the number of phagocytes in the child's blood was excessive, and therefore suppuration was commencing somewhere. When the thighbone was reached, nothing was to be found, but the surgeon had faith in the blood-count, and, penetrating to the interior of the bone, found a small pocket of pus, which, had he not drained it, and dealt with the bone antiseptically, might soon have cost the boy his leg or his life.

The application of Listerism for the protection of motherhood

We have left to the last what is universally recognized as one of the most significant of all applications of Listerism — namely, its protection of motherhood. The destruction of maternal life in lying-in hospitals attracted the attention here of Oliver Wendell Holmes, and of Ignaz Philipp Semmelweiss in Vienna, in the first half of the nineteenth century. They both received the customary treatment of medical reformers who are before their time. Not until late in the 'sixties did Pasteur discover that the too familiar *streptococcus* is the great enemy of motherhood. The epidemics it caused used to sweep away the population of the Paris Maternity Hospital like a plague, and women who had to enter it bade farewell to life; and the bad reputation which the old maternity hospitals so dreadfully earned still interferes with their usefulness, even today. But Listerism has mastered the *streptococcus*. The records of such a hospital as Queen Charlotte's, in London, or the Sloane in New York, will nowadays go on for years without the occurrence of a septic case.

VOLCANIC CATASTROPHES

The Story of the Great Historic Surprises from Vesuvius, Bandai-san, Krakatoa, Mont Pelée and Mauna Loa

SCENES WHEN FIRE RAINED FROM THE SKY

IN a later chapter is described the general phenomena of volcanic eruptions; we will now give brief accounts of some of the great volcanic catastrophes.

One of the most notable eruptions of historical times was the terrible outburst of Vesuvius in 79 A.D. — the eruption that buried the great cities of Pompeii and Herculaneum. For centuries the monster had slumbered. A hundred and fifty years before the great eruption, the gladiator Spartacus, with seventy followers, took refuge in its crater, and, when besieged by the prætor Claudius Pulcher, escaped by climbing down with the aid of ropes made of vine branches. No one thought of the mountain as a volcano, unless, perhaps, a few observant men, such as the historians Strabo and Diodorus Siculus, who noticed the cindery aspect of the surrounding country. Up almost to the crater of the volcano were fields, vineyards, orange groves and prosperous villages, and at its base were the cities Herculaneum and Pompeii, with their villas and palaces, their theaters and temples. No dread of eruptions disturbed the inhabitants of this happy land, which basked in the sun and "laughed fertility". Yet they had many warnings before the disaster. The monster stirred in his sleep; his great flanks heaved; the land was shaken again and again. For sixteen years this went on, until, finally, a violent shock, on August 24, 79 A.D., was followed by the great eruption.

The historical documents describing the eruption are, of course, the famous letters of the younger Pliny, and we cannot do better than quote part of one to Tacitus.

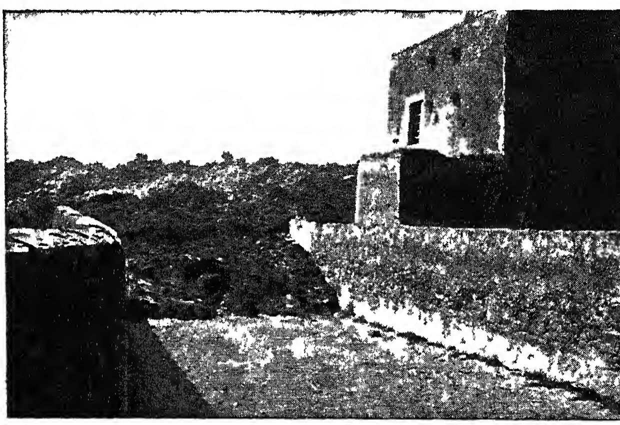
"Being got at a convenient distance from the houses, we stood still in the midst of a most dangerous and dreadful scene. The chariots which we had ordered to be drawn out were so agitated backwards and forwards, though upon the most level ground, that we could not keep them steady, even by supporting them with large stones. The sea seemed to roll back upon itself, and to be driven from its banks by the convulsive motion of the earth. It is certain at least the shore was considerably enlarged, and many sea animals were left upon it. On the other side a black and dreadful cloud bursting with an igneous serpentine vapor darted out a long train of fire, resembling flashes of lightning but much larger. . . . The ashes now began to fall upon us, though in no great quantity. I turned my head, and observed behind us a thick smoke, which came rolling after us like a torrent.

"I proposed, while we yet had any light, to turn out of the high-road, lest we should be pressed to death in the dark by the crowd that followed us. We had scarce stepped out of the path when darkness overspread us, not like that of a cloudy night, or when there is no moon, but of a room when it is shut up and all the lights extinct. Nothing then was to be heard but the shrieks of women, the screams of children, and the cries of men; some calling for their children, others for their parents, others for their husbands, and only distinguishing each other by their voices; one lamenting his own fate, another that of his family; some wishing to die from the very fear of dying; some lifting their hands to the gods, but the greater part

imagining that the last and eternal night was come which was to destroy the gods and the world together Among them were some who augmented the real terrors by imaginary ones, and made the frightened multitude falsely believe that Misenum was actually in flames

"At length a glimmering light appeared, which we imagined to be rather the forerunner of an approaching burst of flame, as in truth it was, than the return of day However, the fire fell at a distance from us, then again we were immersed in thick darkness and a heavy shower of ashes rained upon us, which we were obliged every now and then to shake off, otherwise we should have been crushed and buried in the heap

"I might boast that during this scene of horror not a sigh or expression of fear escaped from me, had not my support been founded in that miserable though strong consolation that all mankind were involved in the same calamity, and that I imagined I was perishing with the world itself



LAVA ADVANCING DOWN A VILLAGE STREET

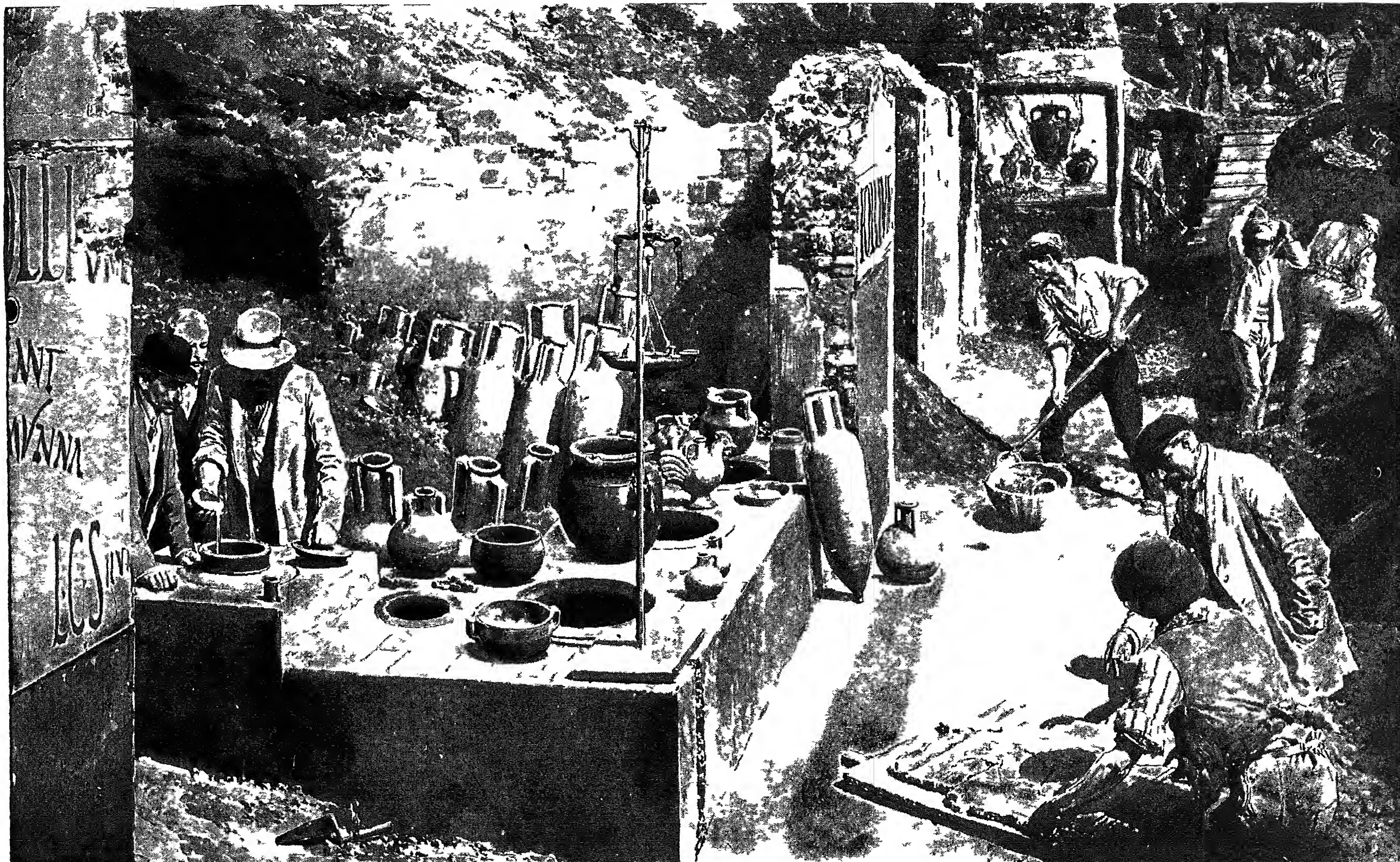
"At last this dreadful darkness was dissipated by degrees, like a cloud of smoke, the real day returned, and soon the sun appeared, though very faintly, and as when an eclipse is coming on Every object that presented itself to our eyes — which were extremely weakened — seemed changed, being covered over with white ashes, as with a deep snow"

This is a picturesque and interesting narrative, but strangely enough Pliny does not mention the destruction of Pompeii and Herculaneum which occurred during the very hours he describes Pompeii was buried beneath layers of ashes, cinders and stones, in some places sixty or seventy feet deep. Herculaneum was drowned in volcanic mud So deeply and completely were these cities buried that during the Middle Ages their very existence was forgotten It was one of the most terrible catastrophes in human history

After that great eruption Vesuvius was in an explosive state for many years, but in the seventeenth century it seemed quite dead, and cattle grazed and wild boars had their den within its crater Again it proved active, six months of earthquakes in 1631 were succeeded by a terrific eruption, which blew away the whole top of the mountain and scattered ashes for hundreds of miles Seven streams of lava poured from the crater, destroying several villages, among them Resina, which had been built over the buried Herculaneum For the next hundred and fifty years there were many eruptions great and small, and the mountain underwent frequent alterations in shape and size In 1794 a great fissure was formed nearly half a mile long, and a tremendous torrent of lava ran down to the sea All through the nineteenth century periodic earthquakes and volcanic paroxysms continued Altogether, in the eighteenth and nineteenth centuries, Vesuvius was in eruption about fifty times, or about once every two years

Within quite recent times there have been two great eruptions, one in 1872 and one in 1906 That of 1872 was carefully observed by Professor Palmieri In all respects it was typical It was preceded for some time by earthquake shocks and increased volcanic activity, and then suddenly, on April 24, the eruption began On this occasion the column of vapor rose to a height of about 20,000 feet, and masses of soft lava, known as "volcanic bombs", were thrown up over 4000 feet

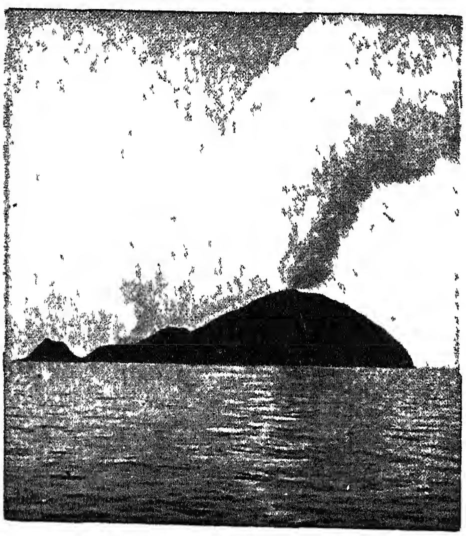
PRESERVED INTACT FOR CENTURIES UNDER THE ASHES FROM VESUVIUS



A CANTEEN, OR WINE BAR, WITH ALL ITS FITTINGS AND UTENSILS, DISCOVERED BY THE EXCAVATORS OF POMPEII

above the mouth of the crater Great streams of lava poured down the mountain, and lava oozed from numerous fissures in the cone, so that Palmieri described it as sweating fire. The lightning flashes in the vapor column were very vivid, and the bellowing and roaring of the explosion could be heard miles away. Several villages were partially destroyed, but most of the inhabitants escaped.

In April, 1906, Vesuvius was in eruption again, and six lava streams poured down the mountains. Professor Matteuci, then in charge of the Vesuvius Observatory, reported on April 8: "The eruption of Vesuvius has assumed extraordinary proportions. Yesterday and last night the activity of the crater was terrific, and is increasing. The neighborhood of the observatory is completely covered with lava. Incandescent rocks are being thrown up by the thousands to a height of 2400 or even 3000 feet, and, falling back, form a large cone. Another stream of lava has appeared. . . . The noise of the explosion and of the rocks striking together is deafening. The ground is shaken by strong and continuous seismic movements, and the seismic instruments threaten to break."



STROMBOLI AWAKE

On April 9 he reported that: "The explosive activity of Vesuvius, which was so great yesterday, and was accompanied by very powerful electric discharges, diminished yesterday afternoon. During the night the expulsions of rocks ceased, but the emission of sand increased, completely enveloping me, and forming a red mass from 6 to 10 centimeters deep, which carried desolation into these elevated regions Masses of sand gliding along the earth created complete darkness till seven o'clock. Several blocks of stone broke windows in the observatory"

Much more sand and dust were discharged than during the previous eruption, and all the roofs of the houses in Naples were covered with a fine red dust Vesuvius, therefore, has had a pretty violent past, and in the last few years there have been several great eruptions with copious lava flows.

Other well-known volcanoes in the Mediterranean are Etna, Stromboli, Santorin and Vulcano.

Bandai-san, or Kobandai-san, in Japan, is not so well known as Vesuvius, but this is not surprising, since, for at least a thousand years, it cultivated a masterful inactivity, and peasants worked daily in its green forests without the least foreboding of a fiery doom Probably there had been small local upheavals during the intervening centuries, but nothing like a great eruption Bandai-san, like Krakatoa, is really a group of peaks which are the remains of an ancient colossal volcano, and, according to tradition, the original massive mountain was split up by a great explosion which buried fifty villages; but so dormant had its volcanic energy been for ten centuries that at the time of the catastrophe a forest occupied the site of the ancient crater.

A terrific explosion took place on July 15, 1888. There were a few rumblings, a severe earthquake, and then suddenly a dense column of steam and dust shot into the air. Explosion followed explosion, darkness covered the land, lightning flashed, and then a mighty avalanche of mud, earth and rocks crashed down the mountainside, burying villages as it went, and devastating an area of 27 square miles. Isurumaki, a Japanese priest, who had a miraculous escape from death, gives the following interesting account of his

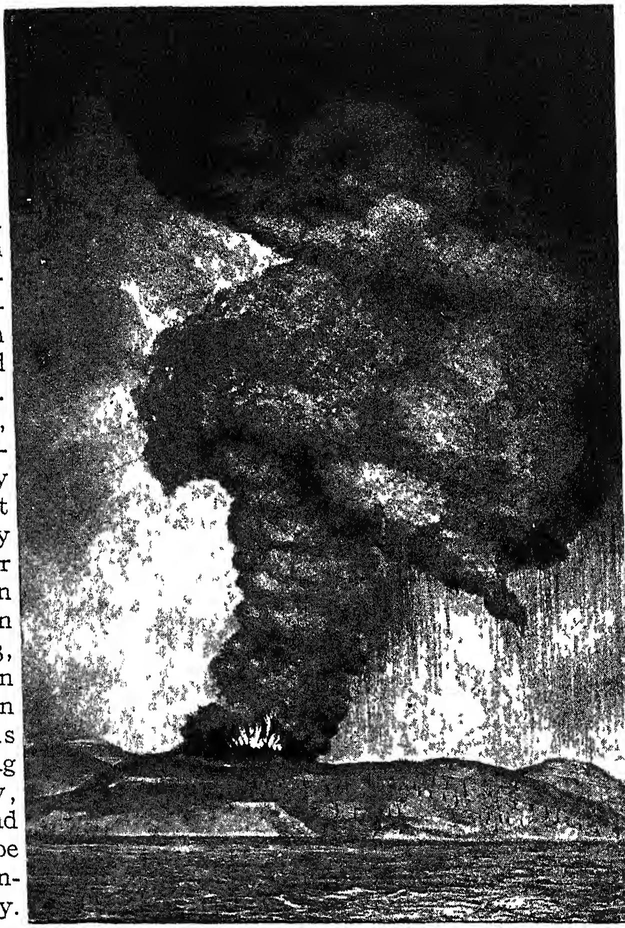
experiences: "The morning of the 15th, which was the fatal day, dawned with a bright and pleasant sky. . . . At about eight o'clock, however, there was a fierce convulsion of the ground, and we all rushed out of the house. In about ten minutes, while we were fearfully wondering what was the matter, a terrible explosion suddenly burst out from the slope of Kobandai, about a quarter of a mile above a place at which steam had been issuing from time immemorial. This was followed by a dense mass of black smoke, which ascended into the air, and immediately covered the sky. At this time showers of large and small stones were falling all about us. To these horrors were added thundering sounds, and the tearing of mountains and forests presented a most unearthly sight, which I shall never forget as long as I live. We fled in all directions, but before we had gone many yards we were all thrown prostrate to the ground. It was pitch dark; the earth was still heaving beneath us; our mouths, noses, eyes and ears were all stuffed with mud and ashes. We could neither cry out nor move. I hardly knew whether I was dead or in a dream. Presently a stone fell on my hand, and I knew that I was wounded. Imagining that death was at hand, I prayed to Buddha. Later I received wounds on my loin, right foot and back. After the lapse of an hour the stones ceased to rain, and the atmosphere had cleared from darkness to a light like moonlight. Thinking this a fine opportunity to escape, I got up and cried, 'Friends, follow me!' but nobody was there. When I had descended about half a mile, there was a second explosion, and a quarter of a mile further on a third explosion, and ashes were ejected, but no stones."

THE STEAMING SLOPES OF BANDAI-SAN, JAPAN

The most striking feature of this explosive eruption was the immense amount of earth and stones that was discharged, much of it coming down like a landslide. The mountain was simply pulverized. Part of it was hurled into the air, and part of it slid down like an avalanche of mud, earth and rocks, mainly earth and rocks, with here and there huge boulders As is usual in volcanic explosions, a great quantity of dust was shot forth, and covered the country for miles around.

The enormous volume of solid matter strewn over the country amounted to nearly 1587 million cubic yards. It filled up all the ravines and gorges, engulfed all familiar landmarks, dammed up several rivers, converted twenty-seven square miles into a desert and buried four villages, and partly covered seven more. The loss of life, however, was comparatively small; only 461 persons were killed, including 92 who fled from a safe hamlet and were all struck down within a few yards. An interesting feature of the eruption was the terrible blast of air driven before the explosions of steam. Houses were leveled, and trees were torn up by the roots or stripped of leaves and branches and left standing bare as telegraph poles. Another interesting feature was the multitude of conical, basin-like holes made in the ground by falling stones.

The 1883 eruption of Krakatoa requires special mention, for it is probably the greatest explosive eruption in historical times. The volcano was situated on an island in the Sunda Strait, between Sumatra and Java, a strait connecting the China Seas with the Indian Ocean. This island, with several others, is the remnant of an ancient volcano which was probably about 10,000 feet high, and had a crater about 25 miles in circumference. For more than two hundred years the island had rested from its volcanic labors; it was covered with rich vegetation and dense forests. Then, in 1880, earthquakes began, and they were no slight tremors, for they were felt as far off as northern Australia. On May 20, 1883, the eruption proper began with sounds like the firing of artillery, which were loud enough to be heard a hundred miles away. Next day ashes were sprinkled on both sides of the straits. On May 26, a party from the mainland visited the islands, and found them covered with a white dust like snow, while a column of vapor 10,000 feet high was rising into the air, and scattering showers of dust and pumicestone. All through June, July and August this state of affairs continued, till finally, on August 26 and 27, the culmination of the eruption was reached.



A PHOTOGRAPH OF KRAKATOA TAKEN ON MAY 27, 1883
Reproduced from *The Eruption of Krakatoa*, by permission of the Royal Society

The Sunda Straits are on the route of trading vessels, and captains and passengers of ships on the spot at the time have given us most information of the final catastrophe. Captain Wooldridge, of the *Sir R. Sale*, writes that on the 26th the sky presented "a most terrible appearance," and that the cloud above the mountain was like an immense pine, the stem and branches formed of volcanic lightning. After sunset the cloud looked like a "blood-red curtain with edges of all shades of yellow," and lightning zigzagged through it. Captain Watson, of the *Charles Bal*, tells of chains of fire that ascended into the sky, and of "balls of white fire" which continually rolled down the mountain. During the great outburst startling electrical phenomena occurred. A peculiar pinkish flame came from the clouds, and balls of fire studded the mastheads and yardarms of the two ships. The mainmast conductor of the *G. G. London*, fifty miles away, was struck by lightning six times, and "the mud rain which covered the masts, rigging and decks was phosphorescent, and on the former presented the appearance of St. Elmo's fire". The natives were so frightened by it, thinking it the work of evil spirits, that the Europeans were left to drive the machinery for themselves.

All day on August 27 the *Northam Castle* and three vessels mentioned were in pitch darkness, and under a continual rain of pumice-stone and dust. So violent were the explosions that they were heard three thousand miles away, and they caused some of the most tremendous air-waves that have ever been known. Windows were broken, walls cracked, lamps overthrown, gas-jets extinguished a hundred miles away and some air vibrations traveled several times round the globe. By the sudden dislodgment of immense volumes of rock below water, vast waves were sent sweeping over the adjacent shores of Java and Sumatra at the rate of nearly four hundred miles an hour, and towns and villages were destroyed, two lighthouses swept away, and nearly 40,000 people drowned.

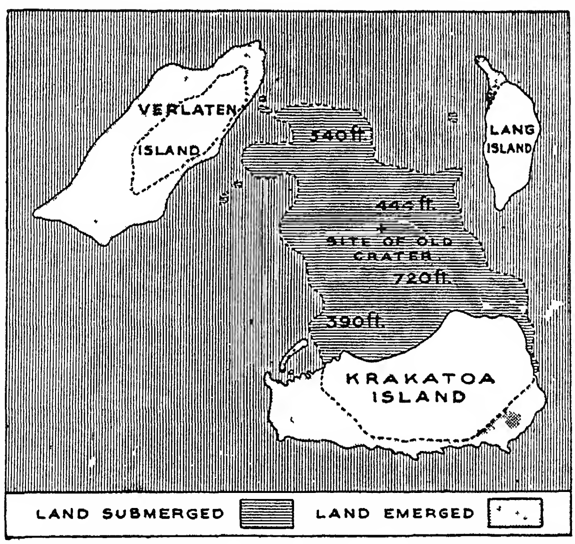


DIAGRAM ILLUSTRATING THF SURFACE CHANGES WROUGHT BY THE KRAKATOA ERUPTION

The Rev. Phillip Neale, one of the few survivors of the town of Anjer, which was overwhelmed by the sea, gives the following interesting account of his escape. He says· "About six A.M. I was walking along the beach. There was no sign of the sun, as usual, and the sky had a dull, depressing look. Some of the darkness of the previous day had cleared off, but it was not very light even then. Looking out to sea, I noticed a dark, black object through the gloom traveling towards the shore. At first it seemed like a low range of hills rising out of the water, but I knew that there was nothing of the kind in that part of Sunda Strait. A second glance — and a very hurried one it was — convinced me that it was a lofty ridge of water many feet high, and, worse still, that it would break upon the coast near the town. There was no time to give any warning, and so I turned and ran for my life. My running days have long gone by, but you may be sure I did my best. In a few minutes I heard the water, with a loud roar, break upon the shore. Everything was engulfed. Another glance around showed the houses being swept away and the trees thrown down on every side. Breathless and exhausted, I still pressed on. As I heard the rushing waters behind me, I knew that it was a race for life. Struggling on, a few yards more brought me to some rising ground, and here the torrent of water overtook me. I gave up all for lost, as I saw with dismay how high the wave still was. I was soon taken off my feet, and borne inland by the force of the resistless mass. I remember nothing more till a violent blow aroused me. Some hard, firm substance seemed within my reach, and, clutching it, I found that I had gained a place of safety. The waters swept past, and I found myself clinging to a cocoanut palm-tree. Most of the trees near the town were uprooted and thrown down for miles, but this one, fortunately, had escaped, and myself with it.

"The huge wave rolled on, gradually decreasing in height and strength until the mountain slopes at the back of Anjer were reached, and then, its fury spent, the water gradually receded and flowed back into the sea. The sight of those receding waters haunts me still. As I clung to the palm-tree, wet and exhausted, there floated past the dead bodies of many a friend and neighbor. Only a mere handful of the population escaped. Houses and streets were completely destroyed, and scarcely a trace remains of where the once busy, thriving town originally stood.

Unless you go yourself to see the ruin, you will never believe how completely the place has been swept away Dead bodies, fallen trees, wrecked houses, an immense muddy morass and great pools of water are all that is left of the town."

The dust of the explosion is stated to have reached a height of 17 miles, and gave rise to marvelous sunsets and sunrises all over the world. The Hon. Rollo Russell described the sky at Cannes on January 10, 1884, as follows. "Orange ordinary glow in S. W. near horizon; above this a greenish-bluish white arc, then a beautiful yellow band; then, up to the zenith, a very beautiful lilac tint. All these colors were of extreme softness, and, though not so striking as some of the sunsets in December, in point of beauty they were quite unsurpassable and of superb magnificence in their further progress. The pink, purple or lilac now retired in the most steady and regular manner towards the horizon, and were visible to the end; thirty-five minutes after sunset the arc was formed of the inner part, which from steel-blue had gone through olive-green to yellow, the middle yellow, and the outer purple. Through the fringe of this Venus shone beautifully. The horizon — about a quarter of the circle — was deep yellow. The purple part being the smallest was flooded, except at the edge, by the orange light, which shone in a grand arc for a long time with great splendor, casting shadows. In about fifty-four minutes the primary glow was gone, having sunk in a deep red band. The eastern sky during the first part of the display was a glorious deep blue, then very dark purple-blue, and, lastly, only illumined by the silver moon."


A STEAMER CARRIED INLAND BY KRAKATOA'S SEA WAVE

Monsieur de Montessus wrote from San Salvador, in Central America: "The remarkable sunsets have been seen here since the last days of November, 1883. About half an hour after sunset, and an hour before sunrise, the horizon is gradually illuminated with a magnificent coppery-red tint, very constant in color, very intense, and lasting on the average twenty to twenty-five minutes The moon, when circumstances allowed of it — that is, when her altitude did not exceed 15 degrees — was colored a magnificent emerald-green, and it was extremely beautiful to see it at the time of gray light, when its disc was of a pale green, with its crescent horn deep green in the midst of an immense crimson curtain. Venus only was able to penetrate the curtain, and was also green."

Not only were there green moons, but also blue and green suns. On September 12, 1883, a government official wrote from Ceylon: "The sun for the last three days rises in a splendid green, when visible — *i e.*, about 10 degrees above the horizon. As he advances, he assumes a beautiful blue, and as he comes further on looks a brilliant blue resembling burning sulphur. When about 45 degrees it is not possible to look at him with the naked eye, but even when at the zenith the light is blue, varying from a pale blue to a light blue later on, somewhat similar to moonlight, even at midday. Then, as he declines, the sun assumes the same changes, but *vice versa*. The moon, now visible in the afternoons, looks also tinged with blue after sunset, and, as she declines, assumes a very fiery color 30 degrees from the zenith."

The Krakatoa eruption was certainly in some respects unique, but as a tragedy

KILAUEA VOLCANO IN ERUPTION

Photo 11th Photo Section Air Corps, U S A

Kilauea the famed volcano on the side of Mauna Loa with reserved seats for watching a performance

THE RUINS OF ST. PIERRE, MARTINIQUE, AFTER THE BLIGHTING ERUPTION OF MONT PELEE

ALL THAT WAS LEFT OF ST. PIERRE, THE PEARL OF THE LESSER ANTILLES—A TOWN OF 25,000 INHABITANTS

it is not to be compared with the eruption of Mont Pelée, in 1902. The island of Martinique, on which Mont Pelée is situated, is one of the most beautiful of the West Indies, and St. Pierre, its chief town, was considered by Lafcadio Hearn "the quaintest, queerest, and the prettiest withal, among West Indian cities". The island was a tropical paradise basking in blue seas, and clad from head to foot in luxuriant vegetation. Even Mont Pelée, though its name signifies bald, was clothed in green, and the old crater on its summit had become a beautiful mountain lake surrounded by ferns and lobelia.

For some time before the disaster of 1902, Mont Pelée had been threatening danger. During all of April steam was seen issuing from a valley on the shoulder of the mountain, and on the 25th there was a slight discharge of ashes, and an exploring party found that an old lake bed was filled with water. On the 30th there were earth tremblings and slight explosions. All these were warnings of impending danger, but the light-hearted inhabitants had little fear, and their chief paper, *Les Colonies*, advertised an excursion to the summit of the mountain on May 4, "if the weather be fine".

On May 2, however, there was a violent eruption with loud explosions, and heavy clouds of condensed steam so that the people began to take alarm, and schools and stores were closed. Soon the streets and gardens were white with falling ashes, and birds dropped dead, killed by noxious gases. Nothing disastrous to human life happened, however, till the 5th, when the side of the new lake was blown out, and its water, rushing down the side of the mountain, carried away trees and rocks, destroyed with a river of mud a big sugar-mill and thirty persons in it, and finally plunged into the sea with such momentum that it raised a huge wave that sunk two yachts, and flooded the lower streets of St. Pierre. Then the alarm of the people grew to a panic, and crowds fled from the town to Fort de France. "It was a flight for safety," says *Les Colonies*, "without knowing where to turn."

The few moments that changed a busy town to a cinder

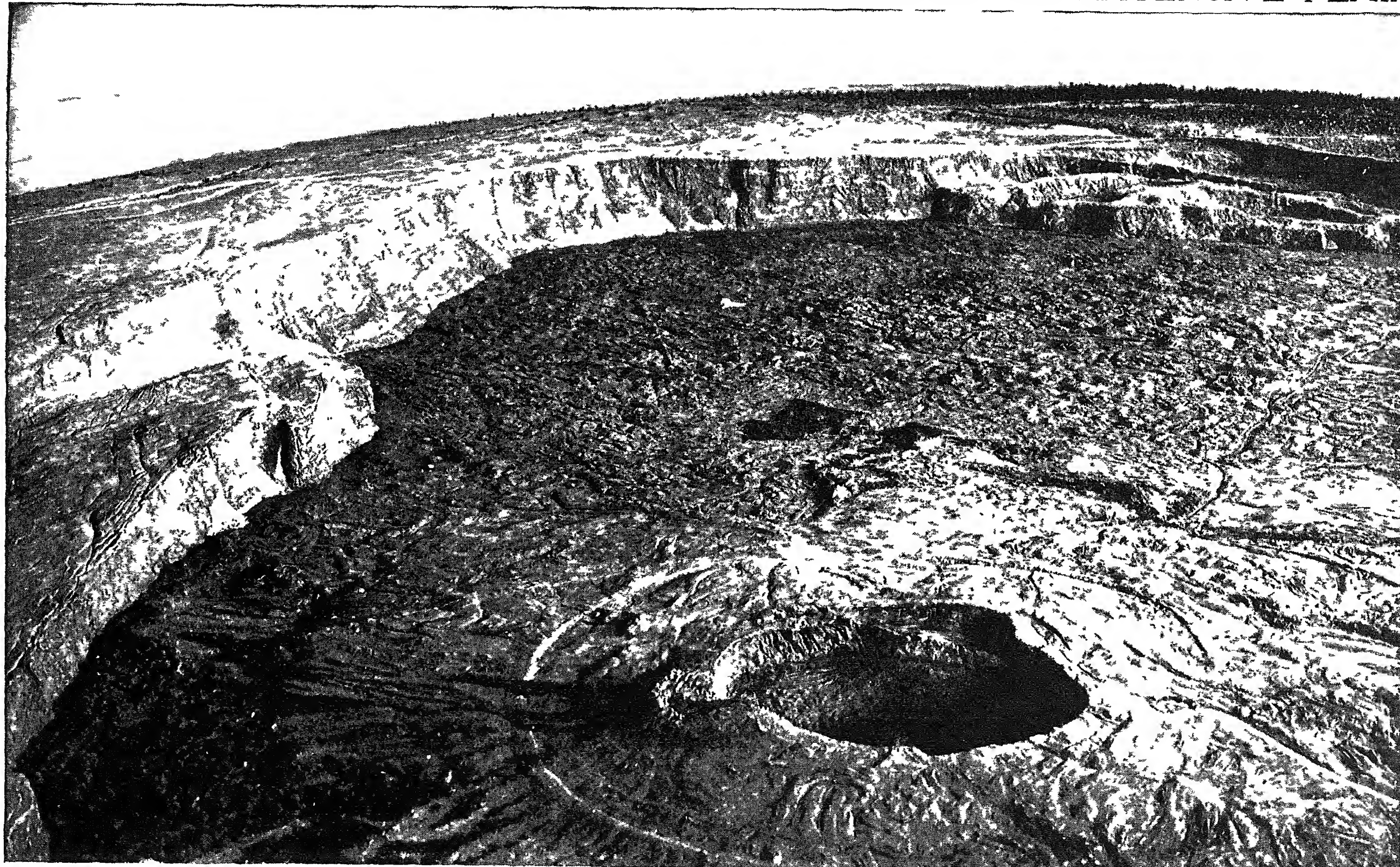
But the crowds did not flee too soon; death was at their heels. At 7:50 on the morning of May 8, the mountain exploded with deafening detonations, and a fiery cloud of intensely hot gases and incandescent particles of rock rolled down upon St. Pierre. In a few moments the town was ablaze, and soon thirty thousand bodies lay dead. Captain Freeman, of the *Roddam*, who watched the terrible tragedy from the sea, saw a few forms running distractedly upon the beach, but death soon caught them, and the "quaintest, queerest and prettiest of West Indian cities" was a city of the dead — a blazing, thundering charnel-house. Torrential rains followed the eruption, and, as Heilprin puts it, "At the end of this time the city was laid in smoldering ruins, coated with ash-paste, and looking as if built of adobe plaster. What had before been the vivid coloring of houses of the tropics was now an ashen gray — the color of earth, cold, bleak and burned."

So thoroughly had death done its work that only one man in the whole city survived, a negro prisoner in the city jail.

The strange fate that left alive one criminal negro

He said that when he was waiting for breakfast, on the morning of May 8, hot air, mixed with ashes, suddenly came through the grating and scorched him. The intense heat lasted only for a moment, and left him fearfully burned. For three days he lay undiscovered, but on the fourth he was heard calling for help, and was liberated. It was certainly an amazing escape. "There perished in St. Pierre the governor of the colony and his wife; Colonel Gerbault, chief of artillery, and his wife; the British and American consuls and their families; twenty-four priests; seventy-one sisters belonging to various Catholic orders; all the professors of the Lycée except five; all the members of the scientific volcano commission except one; and there survived — one criminal negro!"

NOT A MOUNTAIN BUT A CUP-LIKE DEPRESSION IN AN EXTENSIVE PLAIN



Courtesy Geological Museum of Harvard University

KILAUEA CRATER FROM THE SOUTH, SHOWING THE FIRE-PIT IN THE FOREGROUND

A blast that scorched the shipping from the waters

No one knows exactly the nature of the cloud that wrought such havoc, but it certainly was hot gas, probably ejected towards the town under tremendous pressure and with a velocity of over 40 miles an hour. It not only slew as it went, but it tore solid houses to pieces "as children's playhouses of kindergarten blocks would be torn to pieces by the discharge of a thirteen-inch gun"; it uprooted great trees; it dismounted heavy guns: it tossed about heavy boulders and colossal statues Many authorities hold that it was probably a blast of superheated steam, but it may have also contained poisonous gases. Whatever its nature, its force was terrific, its effects devastating.

A second blast of the same nature occurred on May 20, and completed the work of destruction, so much so that "it was impossible to determine whether a particular heap of stones, plaster and debris had been a store, a warehouse, a public building or a private residence". Not only was the town of St. Pierre demolished in this way, but the blast rushed out to sea and capsized and totally wrecked all the vessels in the roadstead except two — the *Roddam* and the *Roraima.* The former parted anchor, and eventually reached St. Lucia with twelve of her officers and men dead and ten others severely burned. The *Roraima* had her masts, funnel, bridge and boats carried away, her decks were swept with stones, pumice and hot ashes, and she was set on fire. Only two of her passengers survived, and twenty-eight out of her crew of forty-seven died from burns and shock. Such, then, was the tragedy of Mont Pelée — one of the most terrible since the world began.

The largest crater of any of the technically active volcanoes in the world

When treating of the Islands of the Main we called attention to the fact that the Hawaiian Islands are of volcanic origin and really volcanic peaks. A few of these Pacific volcanoes deserve special mention. On the island of Maui is Haleakala, 10,000 feet high, with a tremendous crater 8 miles in diameter and 3000 feet deep. According to Dr. Jaggar, Director of the Hawaiian Volcano Observatory, "Haleakala is probably the largest of all craters among volcanoes that are technically known as active." The island of Hawaii itself is a mass of outpoured lava topped by several cones, some of them active, especially the king of volcanoes Mauna Loa or the Great Mountain. It measures nearly 200 miles in circumference at the base and its highest crater, Mokuaweoweo is 13,700 feet above sea level. Though Haleakala has a larger crater Mauna Loa is the greater volcano and ranks as the largest active volcano in the world with eruptions about every ten years. Dr. Jaggar states that "during the last century it has poured out more lava than any other volcano on the globe." The Hawaiian lava is very thin and when it flows over the crater rim or breaks through its side, "it runs in cascades of fiery red fluid rock". The first recorded eruption of Mauna Loa took place in 1823; this and the many succeeding outbreaks consisted mainly in the quiet discharge of enormous flows of lava. In 1855 a lava torrent three miles wide rushed down the mountain, spread out on the plain into a lake seven miles in diameter and then "divided up into a network of rivers which burnt their way through the forests and leaped precipices in a succession of cataracts and rapids". In 1859 the lava stream began to run on January 23, reached the sea, 33 miles away, in 8 days, and continued to flow into it for 10 months. On the southeast flank of Mauna Loa and 4000 feet above sea level, very easily accessible, is Kilauea, probably the most remarkable continuously active crater known. This crater, now included in the Hawaiian National Park, is sometimes called the lower crater of Mauna Loa, but it appears to be quite independent of the great mountain in its action. Kilauea, about 9 miles in circumference, is a black, slightly undulating plain of congealed ropy lava inclosed by a cylindrical basaltic wall varying from 200 to 700 feet in height.

Within the plain is a deep, fiery pit called Halemaumau whose surface of varying area melts and solidifies, rises and falls This pit is sometimes filled with heaving lava, boiling from the escape of gases, and sometimes empty to a depth of 1000 feet Frequently when the pit mass is thoroughly melted, red- and white-hot lava jets 10 to 50 feet high are thrown from its surface. Kilauea's first recorded eruption was in 1789 and consisted chiefly of cinders and sand. But in 1840 it discharged a flood of lava from one to three miles wide and from 12 to 200 feet deep It flowed 30 miles in four days and leaped as a cataract a mile wide into the sea. For three weeks this "Mississippi of molten material" rushed through deep valleys into the sea, which boiled and steamed where the river of fire entered it. For twenty miles along the coast the waters were hot and the lurid glow of the flowing lava could be detected at night by ships 100 miles away. So we rightly say that Mauna Loa with its double crown of Mokuaweoweo and Kilauea surely deserves the title of "King of Volcanoes"

The earth is by no means so solid and so stolid as it seems Its crust may be cold, but its heart is prodigiously hot. From the time when its molten waves surged beneath the sun it has never been quite *terra firma*. Tremendous, massive changes in the contours of its land and water have continually occurred. Mountains have sunk and risen, seas have waxed and waned, whole continents have appeared and disappeared. Even now the Andes and Scandinavia and Scotland and most of the coral islands seem to be slowly rising, and other parts of the world seem to be slowly subsiding.

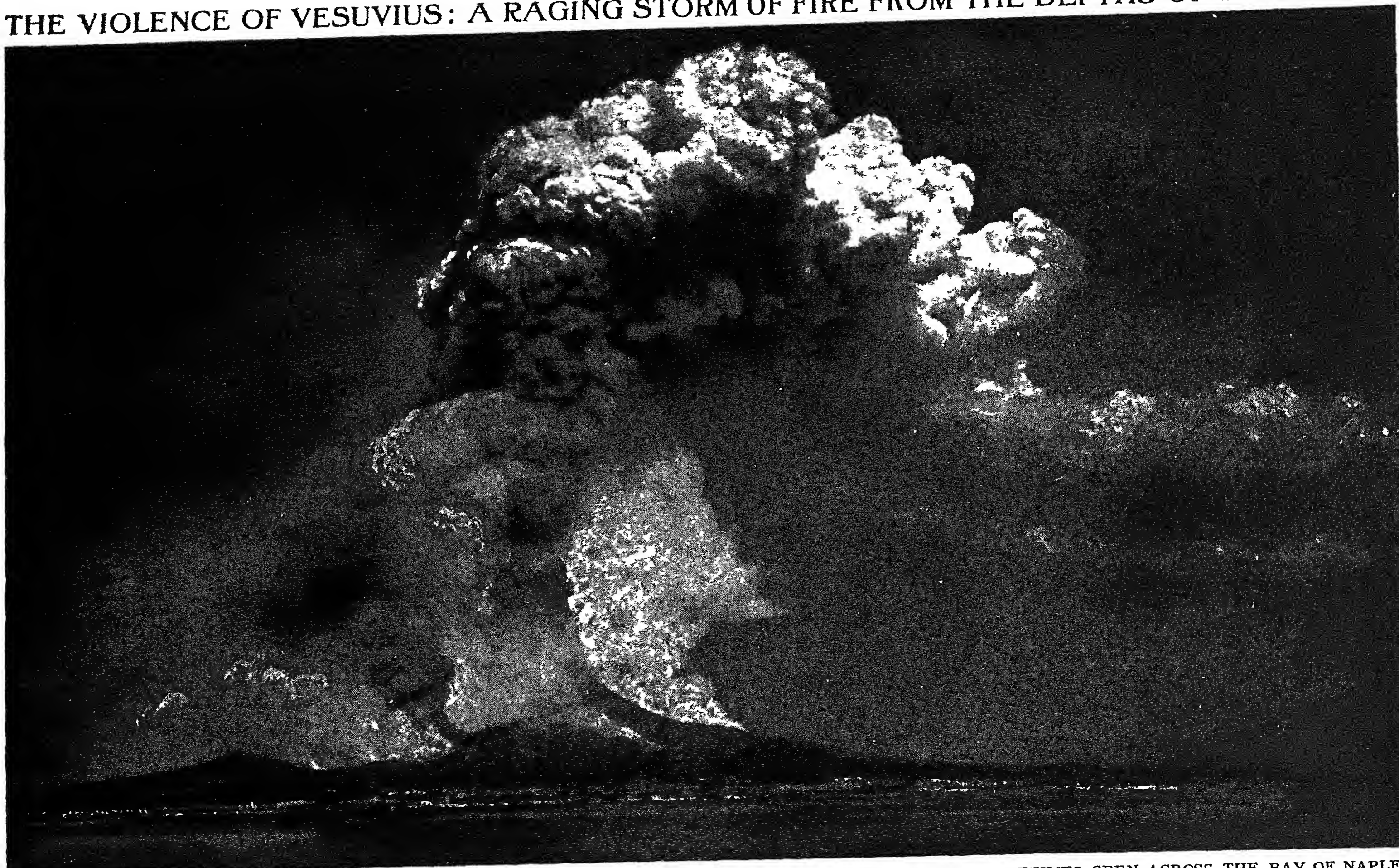
But apart from these great, slow, massive see-saw movements, the crust of the earth is subject to more or less sudden vibrations, quiverings, quakings. Constantly the earth is jarred, and jolted, and tugged; twice a day not only its

Photo from Wide World Photos

THE 1923 EARTHQUAKE IN JAPAN

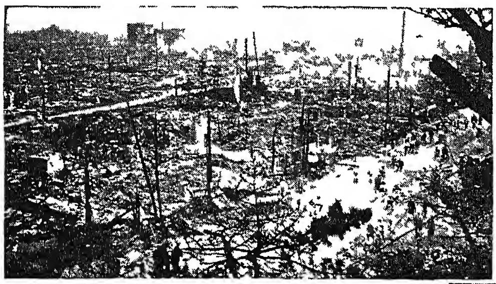
This scene of devastation marks the site of the Fuji Cotton Spinning Mills at Koyama, south of Tokio, where hundreds of operatives were trapped under the mass of brick and iron of the falling walls and roof.

THE VIOLENCE OF VESUVIUS: A RAGING STORM OF FIRE FROM THE DEPTHS OF THE EARTH



SUCH A SIGHT AS THIS IT WAS THAT POMPEII LOOKED UPON; SUCH A SIGHT IT IS THAT EVEN NOW IS SOMETIMES SEEN ACROSS THE BAY OF NAPLES

waters but its continents and mighty cities are lifted and let fall by the moon; and no doubt the crust responds to changes of atmospheric pressure, and to the pounding of the tides. The more noticeable wave motions in the earth's crust are termed earthquakes, and we might expect some of these as a result of violent volcanic eruption Such, in fact, is the case, but these movements are slight and much restricted in area. Still it is popularly



BUSINESS CENTER, TOKYO

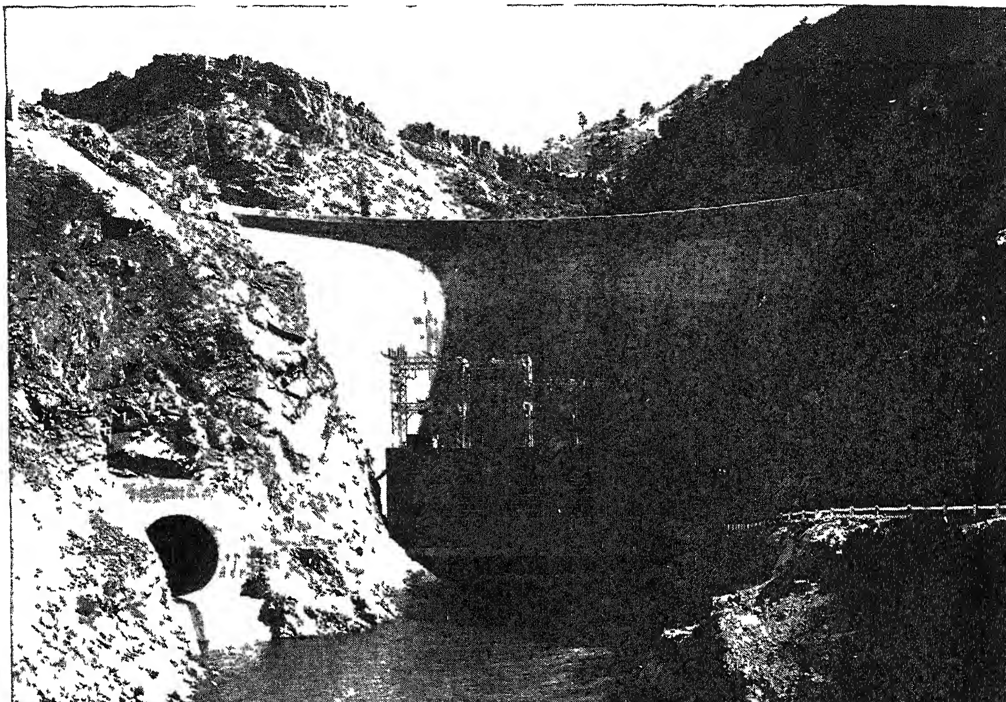
believed that volcanic eruptions and great earthquakes are directly connected. This supposed connection was first disproved in Japan by the work of Milne, the English pioneer seismologist. Omori, the greatest authority in this matter, recently deceased, remarked that "a volcanic district may be assumed to be free from the visitation of a great destructive earthquake whose area is extensive and whose intensity is sufficient to destroy properly constructed wood or iron buildings." The subject of earthquakes is elaborately treated in another section, but we may, without repetition, note briefly some of the great quakes of modern times In 1887 there was a very violent shock in northern Mexico, extending through most of New Mexico and Arizona, and in 1899 southern Alaska was badly shaken, but as both of these districts were thinly settled the loss of life and damage were very slight. In 1906 central California suffered, and especially San Francisco, when 1000 lives were lost and much property was destroyed by fire following the shock. In 1907 Kingston, Jamaica, was partially wrecked, and there were many changes in its coast line and harbor. In 1908, Messina and Reggio, two cities on the narrow strait that separates Sicily from the mainland, were completely destroyed with 100,000 direct victims of the earthquake. The most extensive quake

THE AFTERMATH AT YOKOHAMA

Photos from Wide World Photos
THOUSANDS BURNT AT HONJYO, TOKYO

ever reported was that of Assam, India, in 1897, destructive over 150,000 square miles and distinctly felt over an area of 1,750,000 square miles. In intensity, however, and in vital and financial loss the Japanese quake of September 1, 1923, exceeds all the others. The first reports from the scene of disaster were much exaggerated, but official figures given two months later show the magnitude of the catastrophe. The total area affected by the quake, the subsequent sea wave and fire was about 9000 square miles. The population in this area was nearly 8,500,000; and of these 200,000 were killed, 250,000 reported missing and injured and 2,000,000 rendered homeless, mainly in Tokyo and Yokohama. Scarcely any undersea changes have been detected in Tokyo Bay and very little surface change in the shaken area.

TWO UNITED STATES FEDERAL PROJECTS



Above, Seminoe Dam, on the North Platte River, 37 miles northeast of Parco, Wyo This irrigation, flood control, and power dam was completed in 1938 Height, 295 feet, crest length, 525 feet Below Grand Coulee Dam, 92 miles west of Spokane, Wash, on the Columbia River. It is used for irrigation, flood control, and power Completed in 1942. Height, 550 feet, crest length, 4173 feet. (See page 2178.)

DAMS

WHILE THE ART of dam construction is coeval with civilization when the mountain stream spending itself in the arid plain was diverted for irrigation, the present century has witnessed the greatest development in this branch of engineering. It is generally agreed that the peak of the "era of dam-building" was reached in 1936—having begun in 1900. Bold advances in height and bulk of the structures have been particularly noticeable during the later years of the period, but there is still no lack of originality in design, and in the application of acknowledged engineering principles.

The International Dam Congress, a subdivision of the World's Power Congress held at Stockholm in 1933, met in Washington in September, 1936, in a long and studious review of the science and practice of dam building, with a large corps of eminent speakers, many of them from abroad. Their report presents their subject under five divisions: (1) Joints in dams; (2) Facing of masonry and concrete dams; (3) Special cements; (4) Foundations; (5) Stability of earth dams. The consensus of the Congress as to contraction joints in dams (as distinguished from shrinkage joints) was that these should be provided in all straight masonry and all concrete gravity dams. With respect to arch dams, opinion leaned strongly toward their necessity in the upstream face, and in that only. As to spacing these joints, the meeting was almost unanimous that in concrete gravity dams they should not be more than 50 feet apart. The width approved for transverse shrinkage-gaps varied from two feet as a minimum to eight feet as a maximum—to be decided by the size of the structure; and should not in any case be so wide as to result in excessive shrinkage in the gap itself. A Swedish engineer made the original suggestion that steel reinforcement should be used across shrinkage gaps. As a guard against cracking, it was recommended that the ratio of water to cement should be 1 to 1½; that a lowheat cement be used; that quality of concrete and not speed of construction should govern; and that large-scale experiments should determine the shrinkage to be provided for. For expansion joints it was argued that they be made so as to maintain the blocks forming the dam as independent elements.

Facing on the upstream side of the dam, being designed to check the percolation, has frequently in Europe been an asphaltic cover, sometimes with burlap as a support. It is inexpensive and satisfactory. High quality concrete is also used largely on upstream faces in Europe. However, in cases of frequent freezing and thawing concrete soon deteriorated. Masonry was favored for facing at high altitudes It was, nevertheless strongly argued that facing is a mistake, and that the entire dam should be a tight homogeneous block. Means used to obtain impermeability in Great Britain was to double the cement ratio for the upper two feet of the facing, and place it concurrently with the bulk of the dam, separated from it when laying by steel sheets which are pulled along while the two layers of concrete are still wet, so that they blend into one mass. This facing concrete is increased in density by vibration before it is applied. In Italy, leaky dams are restored by a facing of iron plates. Stone masonry facings in Sweden have failed after a life of 20 to 30 years, and have been replaced by a rich concrete; and this last named material is now favored for the whole mass of a new dam.

Special cements discussed included those of low-heat and moderate-heat

types, silica cements, Portland-puzzolan cements, aluminous cements, and iron cements. High silica cements in Swedish use had shown less cracking. It was decided that special cements are here to stay but that longer experience with them was necessary. Low-heat cement with diatomaceous mixture showed absolutely no cracks in some of the tests.

As to foundations, the importance of the geologic study of the proposed sites was urged. Tests for strength of foundation material are not yet precise enough. Pressure grouting of the underlying strata is frequently practised, and cutoffs and blanketing resorted to where the question of stability is raised.

Earth dams are largely a question of geometry. The persistency of the dam slopes, though important, should be secondary to the consideration of mass stability. The practice of continually checking conditions in the dam's mass during construction (by borings) was advocated.

Earthquake-proof dams

The hazards of building dams in countries subject to earthquakes have been cheerfully assumed by engineers where the demand has been of great moment. The five earth dams under construction during 1936 in the Santa Clara Valley exemplify not only the daring of the builders, but the better understanding of possible earth movements in that tremulous section. Here two of the larger breaks in the California surface, the San Andreas fault and the Hayward fault pass close to the western and eastern edges of the valley, respectively. Movements along both these faults have caused severe earthquakes in recent years. Slips on the Hayward fault number several during a century, the latest being in connection with the great earthquake of 1868. Several times each year minor movements occur in the Hayward fault.

The situation in the Santa Clara Valley was that the 2,000 pumping plants which for 20 years, had been operated to irrigate the 130,000 acres of that highly fertile area, had steadily reduced the water table there, and the cost of this pumping had risen to about $665,000 a year. It was decided to build a storage reservoir on each of the five principal streams entering the valley, the dams to range in height from 100 to 140 feet. The Coyote River is the largest of these streams. It comes into the valley from the east and has worked down into the Hayward fault, so that its dam had to actually straddle this fault. Geological records showed that within the last century the maximum horizontal shift had been 15 feet, and the vertical movements between three and five feet. Although no instance is on record of the destruction of an important modern dam by an earthquake, an intensive study was made as to possibilities. Decision was made that: (1) The water-resisting material of the dam must be of a sort that is not easily ruptured by shock (precluding the use of concrete as an arch, or as a waterproof face or core-wall); (2) the cutoff wall must be carried down further than usual, so that any cracks opening under the foundation will not allow water to pass under the dam during an earthquake; (3) the dimensions of the impervious element must be such that in no conditions could this part of the structure be offset enough to let water through; (4) the impervious element must be protected by weighting it down with granular material which has no resistance to shearing, so that the impervious material cannot slump during an earthquake; (5) the general structure must be such that if the dam is stretched lengthwise, it would instantly close the break before water could establish a channel through it. The five dams were all built of earth compacted with the "sheep's-foot roller" at a pressure of 325 pounds per square inch. All but the Coyote dam have a width of 20 feet at the crest, and the slopes are all 2½ horizontal to one vertical. The upstream face of one of the dams is a layer of loose, dumped rock; on the other four, after the face of the earthfill was planed

off, each was covered with a 12-inch layer of clean gravel as a support for a reinforced concrete slab, four inches thick, laid in panels 16 feet square, with construction joints on all four sides, and weep holes in the centre. This facing aims to give protection from wave wash, span pockets of soft material, and distribute the water pressure uniformly over the body of the dam. The Coyote dam, largest of the five, has a freeboard of 21 feet and stores 30,000 acre-feet of water. The impervious element is a rolled fill 60 feet in width at the top. The cutoff trenches were carried down into hard rock. Outside the impervious section, on both upstream and downstream faces are blankets of clean round gravel 10 feet thick at the top and 90 feet at the base. Outside the gravel zones, blankets of rockfill were placed on both faces, also 10 feet thick at top and 90 feet at base. The normal storage level is 100 feet above the streambed.

The Shing Mun River dam in China, an adjunct to the Hongkong water supply, is built in earthquake country, and evidences the handling of similar problems by British engineers. It has a height of 275 feet, and a crest length of 695 feet at the water level. It is a rockfill dam with an upstream face of rich concrete, divided by vertical bitumen-filled joints, made continuously impervious by kinked copper strips sealed with bitumen. This construction can withstand a large amount of distortion without being destroyed. A cutoff wall, formed by the extension of the face, goes down to impervious rock, and is built of rich concrete carefully placed for maximum density. Back of the face and the cutoff wall is a thrust-block of low grade mass concrete, based on the surface rock, and designed to transmit the water pressure to the rockfill. To secure a uniform transmission of this pressure, a wedge-shaped mass of dry sand is held between these two elements.

Repair work on dams

An example of repair work so extensive as to amount almost to regeneration of the type of structure, was completed during 1936 on the Lake Pleasant Dam of the Maricopa County Municipal Water Conservation District No. 1, located 25 miles northwest of Phoenix, Ariz., on the Agua Fria River. When first built (1928) this multiple-arch dam attracted much attention because of its unusual design. But within a year it began to show serious cracks, and examining engineers recommended cutting down the spillway until the 170 foot dam was reduced to 130 feet. The spillway was cut only 24 feet, which did not stop the cracking, but the cracks were smaller. When the repair work was begun, in 1935, the side walls of the buttresses were badly cracked, and it was determined to so strengthen the structure that the spillway could be restored, and storage of water secured as planned when the dam was built. The repairs consisted of (1) a heavily reinforced addition to the downstream side of the water-slab, so that it became 27 feet thick at the base, tapering to 30 inches at the top; (2) horizontal "floors" of 85-pound T-rails within the hollow buttresses, so arranged as to take the tensile stresses from the new water-slab to rail beams built across the downstream faces of the buttresses; (3) filling the hollow buttresses with mass concrete to 10 feet above the old stream bed. All cracks were filled with cement grout under pressure. The spillway was then restored to a capacity of 157,000 cubic feet per second, the maximum flood for the 1,600 square miles of the drainage area. The result of this repair work has been thoroughly tested.

In preparing the foundation for the Alcova Dam, on the Casper-Alcova project in Wyoming, it was found necessary to drill an aggregate of ten miles (length) of holes in the foundation "rock" and fill them with grout to hold together the mass of rock debris in a former chasm, which was riddled with hot springs. Grouting was done with double-acting piston pumps, to give continous pressure without entrapping air.

The volume of grout used was 200,000 cubic feet.

A novel method of mechanical feed

The engineers of the Water Supply Commission of Boston, planning the new Quabbin dykes on Swift River, at Enfield, Mass., to form a part of the Quabbin Reservoir, specified as part of the construction work the sluicing from borrow pits into a basin whence the material was to be pumped into place. The rate of movement of this material was figured at 5,200 cubic yards per day deposited in place in the dam. However, the successful bidder rejected this method and undertook the handling of the material from the borrow pits dry by truck to the sluice box into which it was fed mechanically and mixed with a constant proportion of water. Thence it passed over a rotary grizzly, and a dredge pump delivered the mixture to the dam through two lines of discharge pipes. The mechanical feed eliminated the usual monitor jet employed in mixing, and many removals of material which would have been necessary if the distribution had been left to gravity. The superior efficiency of the contractor's method made possible the placement in the dam of between 8,000 and 10,000 cubic yards per day.

The power-tamper

A novel implement known as a power-tamper imported from Germany, was given a trial during the year 1936 on construction work then under way on San Gabriel Dam No. 1, being built by the Los Angeles County Flood Control District. Its object is to solidify loose earth in a dam or embankment to a greater degree and more speedily than any other method for achieving the same purposes. With a layer of loose earth nine inches thick, weighing about 90 pounds to the cubic foot the compacting is such that the rammed earth weighs 115 pounds per cubic foot, without the addition of water. The machine has the shape of a truncated cone, with a base of 30 inches in diameter resting on the ground. Within this cone is a 4-cycle single cylinder combustion engine so designed that each explosion lifts the entire bulk, weighing about half a ton, into the air while delivering its downward thrust. As the mass comes down again an added thrust is given, and at the same time the explosion gases which have been admitted to the cylinder are compressed, ready for the next explosion. The mechanism is controlled by an operator through a pair of long handle-bars on one of which is a button which sets off the ignition spark from a small battery carried on the operator's back. The axis of the cone leans somewhat away from the operator, so that the motion is of a leaping character. The average height of the leap is nine inches, and the advance forward is about the same, being guided to some extent by the steering twisting of the handle bars while the cone is in the air. Upon the skill of the operator, readily acquired, depends the number and accuracy of the impacts. The usual number of leaps is 50 per minute, and the area rammed per hour is about 3,000 square feet. The gasoline is carried in a two gallon tank on the handle-bars, and lasts about four hours. The machine has proven especially efficient in ramming newly filled earth close to an upright wall, where heretofore only hand ramming was available. On the same dam, the sheep's-foot roller was rendered much more efficient by moulding the angular sheep's-foot projections into globular forms.

New dams for Connecticut River tributaries

Spurred by the annual losses sustained by the State of Connecticut, by high water in the Connecticut River, ten dams and reservoirs were planned for early construction on tributaries of the river, in accordance with a recommendation to Congress by the Board of Engineers for Rivers and Harbors, after receiving the concurrence of the Chief of Engineers. Local agencies provide the necessary land and flowage rights and assume half the construction costs. The river has long been subject to destructive

floods, and the project is only the beginning, as it contemplates a total of 33 dams and reservoirs with combined storage capacity of 931,000 acre feet. The total cost is expected to reach $41,083,000, with annual costs of $2,875,000.

The annual benefits are figured at the saving of $294,000 now lost in damages, and an income of $2,320,000 yearly from power development. The ten dams which are to be built immediately will cost $13,373,000, including dams and water rights, having a storage capacity of 352,500 acre feet, with an annual saving in flood damage amounting to $180,000, and other returns to the amount of $458,000.

New Egyptian dams

The Egyptian government, early in 1936 called for bids to start the construction of two new dams to replace the existing Mohammed Ali barrages in the Nile Delta region, about 12 miles north of Cairo, where the Nile breaks into the two Rosetta and Damietta branches. The function of these Egyptian dams is to raise the level of the river about this point and aid in the distribution of the larger supply of water thus collected into three main canals; (1) the Behera Canal, which supplies irrigating water westward; (2) the Menoufin Canal, which supplies the central country to the north; (3) the Tewfiki Canal supplying the country lying toward Port Said on the east. The new Rosetta dam has 46 openings, and the Damietta dam 34 openings, each 26 feet 3 inches in width, which are normally closed by their mild-steel sluice gates—operated by overhead power-driven machinery. A navigation lock is provided for each dam. The construction is of concrete, and faced with granite from the syenite quarries at Aswan. Over both dams is a roadway for two lines of traffic, and each navigation lock is crossed by a swing bridge.

Warding off the winter ice peril

At the multiple arch dam upon the Ural River near Magnitogorsk, Russia (a structure 3,300 feet in length) the thrust of the winter ice sheet, reaching five feet six inches in thickness, produced a pressure against the face of the dam of 4,600 pounds per square foot. It has been the practice for some years to cut out the ice at the crest of the dam, keeping there a gap of clear water, a daily task during the whole winter. Recently a compressed-air system was installed; a perforated 1½ inch pipe was extended along the inner face of the dam at a depth below the water surface of about 10 feet. The perforations are one-twenty-fifth of an inch in diameter, and bored about 10 feet apart. Compressed air is supplied at the rate of 13,000 cubic feet per minute, by two 60-horsepower compressors, one at each end of the dam. By operating these machines from four to eight hours daily, the body of water next to the dam is kept free from ice; the action of the bubbling air being to bring up to the surface the lower levels of the reservoir water, ranging from 34° to 39° Fahr. in temperature.

Novel dam repairs

In making repairs on two dams in Algeria, a new engineering method was adopted. One of the dams was of insufficient body to withstand the water pressure against it; the other had lost a part of its crest in a flood. In the first case holes 10 inches in diameter were bored at distances of 13 feet along the crest of the dam, reaching to depths of from 72 to 80 feet into the limestone and sandstone foundation. Into these holes were placed cables composed of 630 parallel wires of galvanized steel, forming, with the jacketing rings, an average diameter of 8 inches. The lower ends of these cables were anchored into the foundation rock with cement grout. When this had set firmly, three 440-ton hydraulic jacks were applied to the top of each cable, through a capstan head, and a strain of 1,100 tons was exerted on each while it was being fastened to the head block. The result was to add to the "weight" of the dam a pull of 84 tons per running foot. In building the lost crest of the other dam, it was secured to the lower part remaining, and

anchored to the foundation rock in the same fashion by strained cables.

United States federal projects

Federal projects include the Boulder Dam in Black Canyon on the Colorado River, completed in 1936, and by far the highest dam in the world. Its height above bedrock is 726 feet. Its crest length is 1,244 feet and it raises the water surface of the river 576 feet. It is of the arch-gravity type and contains 3,251,137 cubic yards of concrete, with 4,360,000 cubic yards in dam and appurtenant works. The reservoir (Lake Mead) created by the dam is 120 miles long with an area of 162,700 acres and has a capacity of 32,360,000 acre-feet or 10,544,538 million gallons.

In 1942 the Government completed the Grand Coulee Dam on the Columbia River in the State of Washington. It is 550 feet high and 4,173 feet long. It contains 9,926,005 cubic yards of concrete masonry, about three times the amount in the Boulder Dam. Grand Coulee Dam forms a reservoir which extends 151 miles to the Canadian border and has a capacity of 9,600,000 acre-feet (of water). It is estimated that the water stored in this reservoir will irrigate 1,200,000 acres, an area as large as the State of Delaware. The dam alone has cost approximately $106,000,000, and the entire project which includes irrigation, river regulation, power development, flood control, etc., will cost about $436,000,000. Grand Coulee power was put to its first use when, in March 1941, the station-service generators began to work.

On the North Platte River in Wyoming, in 1938, there were completed two dams—the Seminoe, forming a reservoir with a capacity of 332,368 million gallons, and the Alcova with a reservoir capacity of 61,912 million gallons. The two dams, reservoirs, canal system, power plant, and other project features cost $20,000,000.

Another great project is the Fort Peck Dam on the Missouri River in Montana, costing $123,000,000. It was completed in 1940 except for power development. The maximum height of this dam is 250 feet above the river bed and the length of the main section across the river valley is 9,000 feet. A smaller section, more in the nature of a dike, extends approximately 11,500 feet on the left bank in order to reach the required elevation. The dam contains 109,000,000 cubic yards of earth; 1,600,000 cubic yards of rock, and 4,000,000 cubic yards of gravel. The reservoir created by the dam stores 19,412,000 acre-feet of water, and is 189 miles long, with a maximum clear width of 16 miles and a shore line 1,600 miles in length.

Another great dam was completed in 1938 on the Tygart River in West Virginia at a cost of $15,700,000.

The Bonneville Dam on the Columbia River, 42 miles east of Portland, Ore., completed in 1937, cost $51,000,000. It is of concrete, 1,230 feet long, 180 feet wide at the base, and 170 feet in height.

The Norris Dam, located on the Clinch River in the Tennessee River Valley, cost $13,800,000 ($30,856,000 including ultimate power installation). It is 1,860 feet in length and 265 feet high. The reservoir has a storage capacity of 2,567,000 acre-feet.

Wheeler Dam, on the Tennessee River in Alabama, was completed in 1936 at a cost of about $33,800,000 ($35,265,000 including initial power installation of 129,600 kw.) It is 6,342 feet long and 72 feet high. The reservoir has a storage capacity of 1,150,000 acre-feet.

The Chickamauga Dam on the Tennessee River, seven miles upstream from Chattanooga, was completed in December 1940, making the sixth of the Tennessee Valley Authority's nine main-river multiple-purpose dams for navigation, flood control, and power. The structure has a maximum height of 129 feet with a concrete spillway and two earth embankments totaling 5,794 feet in length.

In 1946 the United States Bureau of Reclamation had (building or under construction) an investment of almost a billion dollars in projects.

OUTER PARTS OF THE SUN

The Sun's Flaming and Pearly Mantles

WE have seen that the great mass of the sun consists of a central core. or nucleus, made up of various elements in the gaseous state. Heated to exceedingly high temperatures and existing under enormous pressure, these gases become very dense without losing their gaseous condition. We have seen, also, that the same gases, in the atmosphere around the sun's nucleus, become comparatively cooled at the surface as they radiate their heat into space. They may at times cool sufficiently to be partially condensed into the liquid condition of droplets, or even into the solid condition of crystals, which form clouds floating in the photosphere.

The outer parts of the sun are ordinarily invisible

We have already considered the interior of the sun and the envelope called the photosphere. By far the greater bulk of the sun, though not of its mass, now remains to be described. For the sun extends outward into space far beyond the dazzlingly bright photosphere. Outside of the photosphere is the chromosphere and outside of the chromosphere is the corona — two vast envelopes of extraordinary beauty and interest. Their light, though it is bright enough in itself, is altogether too feeble to be seen in the presence of the brilliant photosphere. The daylight quenches their radiance just as it veils the light of the stars. For this reason these outermost parts of the sun are ordinarily quite invisible.

The chromosphere and the corona may now be studied at all times

All earlier knowledge of the chromosphere and the corona was gained only through observations during a total eclipse of the sun. For when the light from the photosphere is blotted out by the interposed body of the moon, the chromosphere and the corona, extending beyond the screen set up by the moon, may be seen for a few fleeting moments. Means have now been discovered for seeing the chromosphere at all times when the sun can be seen. Daily observations of the corona are also possible with the photographic telescope known as the coronagraph.

The whole subject of the eclipses of the sun and moon will be considered in some detail in a later chapter, in Volume 7. Here we need only point out that the apparent diameters of the sun and moon, as seen from the earth, are almost exactly equal. The actual diameter of the sun is somewhat more than four hundred times that of the moon, but its distance from the earth exceeds the distance of the moon from the earth by a corresponding degree. It is because of this equality of the apparent diameters that, in a total eclipse of the sun, the disc of the moon may for a moment cover the sun's disc, thus cutting off all the light from the photosphere and so making the outer parts of the sun visible

Observing the outer parts of the sun during eclipses

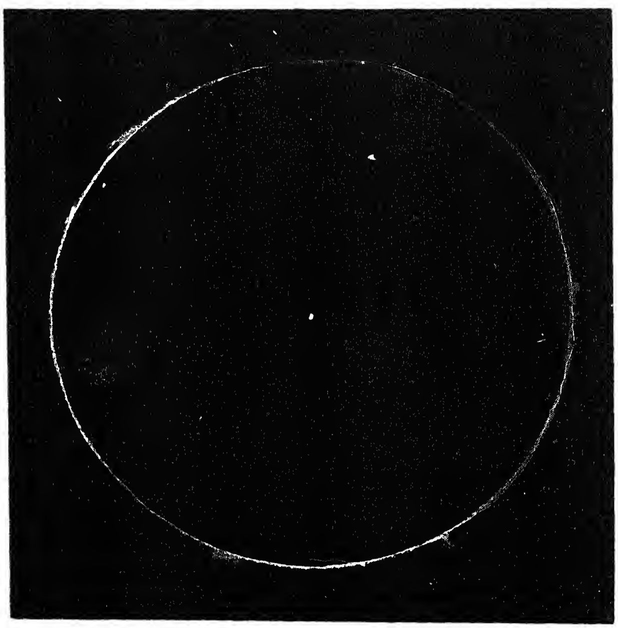
In such an eclipse, if the apparent diameters of the sun and moon were exactly equal, a total eclipse would last for an infinitesimal period of time. But the relative distances of the sun and the moon from the earth vary within certain limits, so that the apparent diameter of the moon is sometimes larger than that of the sun. When this is so, the total eclipse of the sun's disc may last several minutes. In that case the outward parts of the sun may first be studied as the forward edge of the moon cuts off the last of the photosphere; and then again, some minutes later, just before the moon's backward edge allows the first thin line of the photosphere to emerge.

What, then, will be seen at the edge of the sun? Let us suppose the sun's disc to be entirely covered, but just about to emerge from behind the moon. All that we can see at present is the moon, looking like a vast black ball; and streaming outward from behind it is the bright, mysterious glory of the corona. But suddenly, at the edge of the moon where the sun is to reappear, we see a thin curved line of a deep, dusky blood-red color. For a few seconds it glows and widens. Then it is suddenly extinguished, for the edge of the sun's dazzling white disc has emerged, and its accustomed daylight has quenched these lesser lights of the sun's outer parts — the nebulous radiance of the far-flung corona and, the blood-red fires which closely envelop its surface.

More usually the chromosphere does not appear at once as a complete line around the moon, but as isolated points and patches of the same color, emerging from behind the moon like lurid stars, or perhaps suggesting rosy clouds hovering upon the moon's surface. These fiery points and patches, of which there may be one or two or several, grow larger and glow brighter, and are united in the ruddy rim of the sun as the full circle of the chromosphere comes into vision; and, together with it, they swiftly disappear before the returning majesty of daylight

This ruddy mantle of glowing gas is called the chromosphere on account of its brilliant color; and those tremendous projections of flame and fiery cloud, which are here and there and now and then thrown up from the chromosphere, and appear beyond the edge of the moon preceding the emergence of the sun, are, on account of their shape, called prominences or protuberances.

The chromosphere lies above the photosphere, and is divided from it by a well-defined surface. In appearance it is like an ocean of fire, in ceaseless and furious agitation, completely surrounding the sun. Of course, it is not fire in the ordinary sense of the term, for it does not arise from the burning of any gaseous or other materials. But it does consist of flames of incandescent gas, apparently pouring forth at every point of the sun's surface, forming in its lower parts a continuous furnace of great depth, and in its higher parts flaming and spouting upwards in these prodigious prominences. It is now known that the chromosphere is from five to ten thousand miles in depth, and consists principally of hydrogen, with which, however, other gases are present.

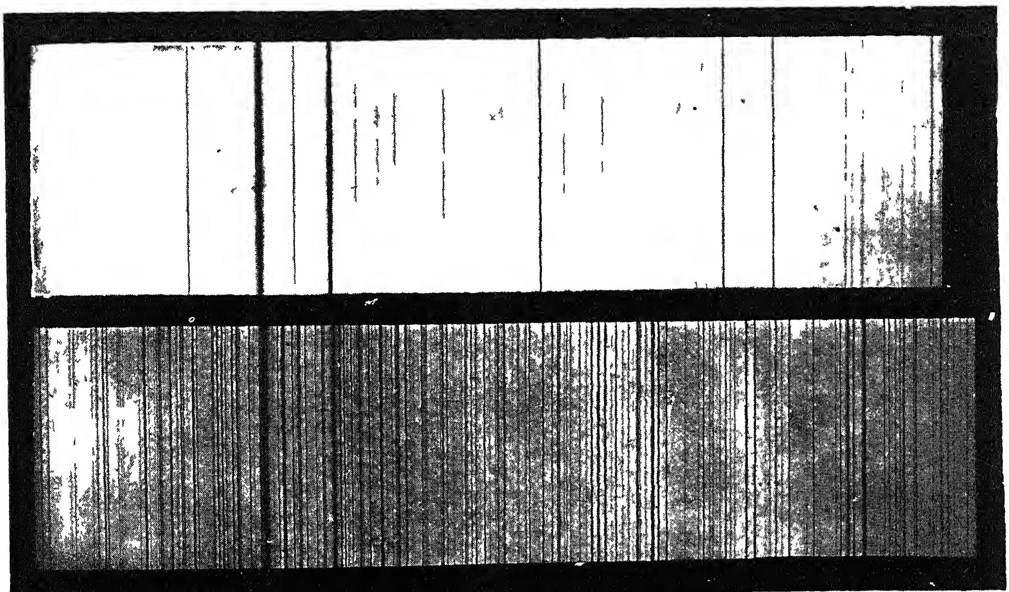


THE CHROMOSPHERE AND PROMINENCES
From a photograph by M H Deslandres.

The vision of the chromosphere obtained at a total eclipse, though very striking, is of course rare, and for but a few seconds. The present knowledge of its nature would have been quite unattainable if an ingenious discovery had not shown that this ruddy envelope of the sun, and its prominences, may be viewed in broad daylight, and even photographed by means of the spectroscope. As the resources of that instrument have been developed, it has been induced to reveal the chromosphere and prominences in three very remarkable ways.

During an eclipse which traversed the Indian peninsula in 1868, several astronomers made a spectroscopic examination of the prominences, and found that these towering flames threw a bright-line spectrum, thus proving that they consisted of incandescent gases or vapors At the same time it was shown that hydrogen was the predominant element in them But one of the astronomers at work, named Janssen, made a far more important discovery. He realized that the spectrum of the chromosphere was so bright that it ought to be visible in ordinary daylight, and, making the experiment next day, succeeded in obtaining the bright lines of the prominences. The report of his discovery reached Europe simultaneously with the announcement of the same discovery by Sir Norman Lockyer, who had solved the problem independently.

In order to see the comparatively faint light of the prominences in the full glare of sunlight, both of these astronomers had devised the same ingenious method. As we saw in the preceding chapter, an incandescent solid or liquid throws a continuous spectrum, but an incandescent gas throws a discontinuous spectrum of bright lines. The light of the photosphere, or ordinary sunlight, is of the former kind, but the light of the chromosphere and prominences is of the latter kind When, therefore, an image of the sun is formed by a telescope, and the slit of the spectroscope is directed to the edge of the sun's disc in the image, the spectroscope receives at the same time the intense light of the sky illumined by the photosphere and the less brilliant light of the chromosphere and prominences That is to say, a continuous spectrum is superimposed upon a spectrum of bright lines But the bright lines are very faint and the continuous spectrum of sunlight is very strong, so that the former are masked by the latter For example, a faint red line from the chromosphere, falling as it does upon exactly the same shade of red in the strong continuous spectrum of ordinary sunlight, must evidently be quite indistinguishable. Yet the observer of the chromosphere wants to see the line spectrum. He has no use for the continuous spectrum; it only serves to obliterate the bright-line spectrum; and yet he cannot shut it out. How is he to deal with it so the bright lines will shine out clearly?

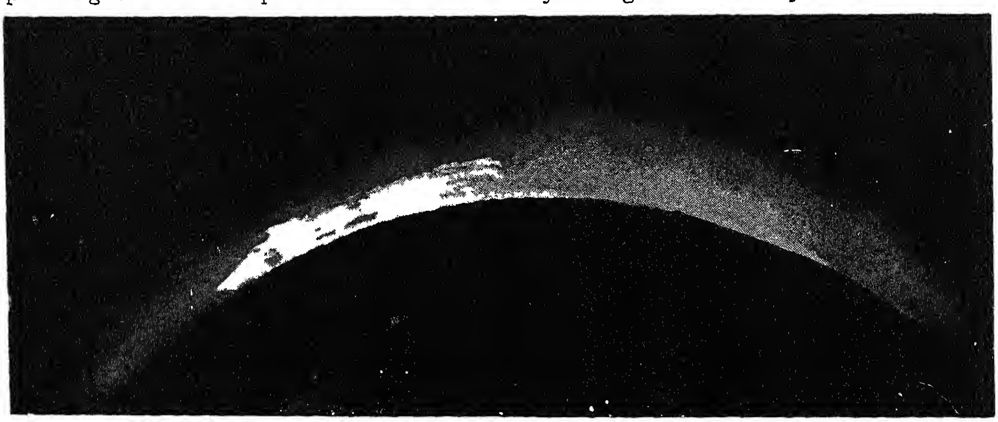


COMPARATIVE SPECTRA OF THE SUN WHEN IT IS HIGH AND LOW IN THE HEAVENS

These two photographs of a part of the spectrum of the sun bring out graphically the meaning of the dark lines The lines are more numerous in the lower band, owing to the fact that the rays pass through a greater amount of the atmosphere of the earth when the sun is low on the horizon These photographs are by Mr George Higgs

The method which Janssen and Lockyer separately devised consists in spreading out the continuous spectrum, and with it, of course, the bright-line spectrum also, until they are both very wide; that is to say, until the red end of the spectrum is very far removed from the violet end. By this process of spreading out, the continuous spectrum becomes fainter and fainter, as the light received through the slit of the spectroscope is distributed over a larger area. But through all the spreading out, the bright-line spectrum remains of the same intensity as it was at first, the only difference being that its lines are removed further and further from one another. It is obvious that if the spreading out of the spectrum is carried on far enough, the continuous spectrum of ordinary sunlight will become so faint as to be negligible, and the bright-line spectrum of the chromosphere and prominences will be seen to stand out with great clearness.

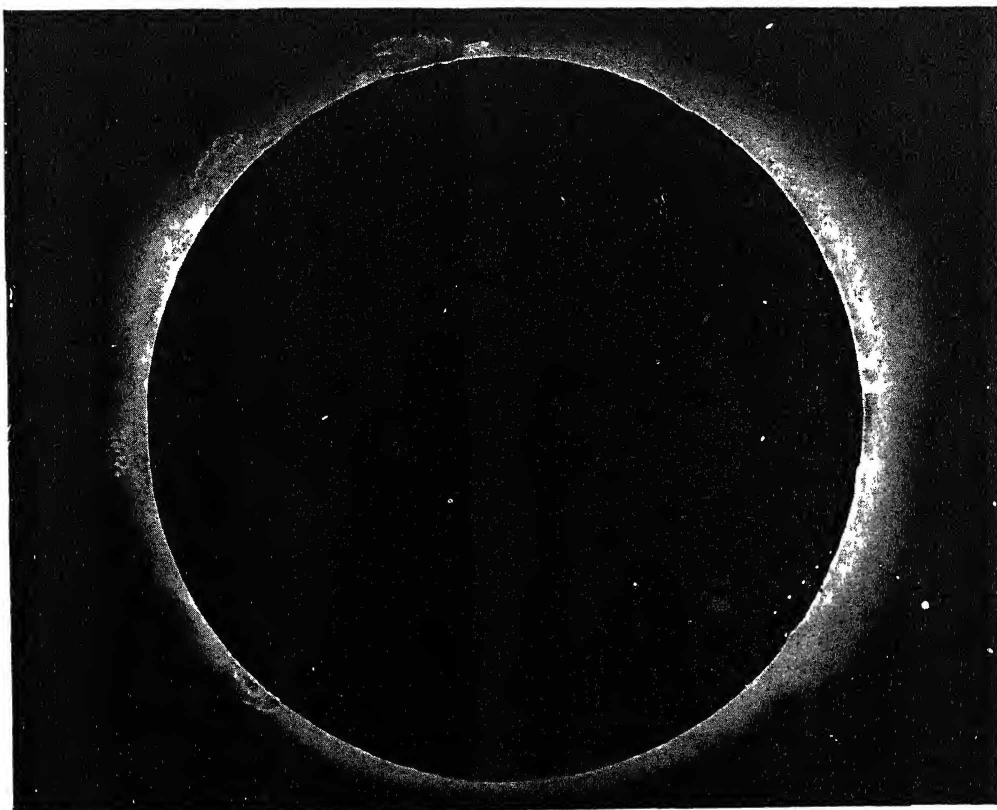
How is the spreading out of the spectrum effected? Very simply: by passing the light through a sufficient number of prisms, each of which separates the variously colored elements of the spectrum to a greater degree than before. In a form of spectroscope often used for this purpose the light is dispersed twelve times, by passing through as many prisms. It may also be asked why, with this repeated dispersion, each individual line of the bright-line spectrum from the chromosphere does not itself become widened out so as to cover a larger area and consequently become fainter. Why should the continued spreading out of the spectrum merely have the effect of separating the lines further from one another, leaving them individually as narrow and therefore as bright as at first? The reason is that each of these lines is spectroscopically of one kind of light only; all the light which it contains is absolutely of the same wave-length. The effect of each prism on any such ray of homogeneous light is to bend it as a whole, but obviously cannot be to bend some of its parts more than others, so as to widen it.



A LARGE SOLAR PROMINENCE SEEN DURING AN ECLIPSE
From a photograph by Comte De la Baume Pluvinel

The spectrum of the chromosphere has received much study. Certain lines, which may be regarded as really characteristic of it, are always present, and indicate hydrogen, helium, calcium and one or two unidentified elements. The corona line, so called because it is given by the light of the corona, is found also in the light of the chromosphere. But this vast envelope of incandescent hydrogen and other gases is subject to great disturbances, especially in the vicinity of sun-spots; and on these occasions there are probably intrusions into the chromosphere of metallic vapors from the photosphere below. This may explain the frequent appearance in the chromosphere spectrum of a great number of lines characteristic of iron, sodium, magnesium, manganese and other metals. But these intruding elements quickly disappear again, leaving only the spectrum proper to the chromosphere.

It was said above that there are three remarkable ways in which the spectroscope is used to reveal the chromosphere and its prominences. With the first of these, the spreading out of the spectrum so as to make it possible to examine the bright lines of the chromosphere in full sunlight, we have already dealt. The second method, which is a development from the first, was devised by Sir William Huggins. It enables the observer to get a telescopic view, directed so as to lie along the edge of the image. As before, ordinarily sunlight will be received along with the far fainter light of the chromospheric flames. As before, the spectrum of the sunlight will be spread out until it is too faint to give any trouble, and the bright lines of the chromosphere will be widely separated from one another. Each of these bright lines is, of course, an image of the slit, in light of some one definite wave-length and therefore of one



THE PROMINENCES ON THE SUN SEEN DURING A TOTAL ECLIPSE

From a photograph by Prof. J. M. Schæberle; the photographs on page 2188 are by Dr. A. Schuster, Sir Norman Lockyer, Mr S. Kostinsky, and Sir W. H. M. Christie

in broad daylight, of the chromosphere and the prominences, so that he can study their form and their changes. He sees through the spectroscope, not their spectrum, but the objects themselves; and is even able to photograph them, thus securing some of their features which the eye cannot perceive.

An image of the sun, as before described, having been formed by a telescope, the slit of a spectroscope of several prisms is pure shade of color. If the observer now concentrates his attention on one of these bright lines, he is actually looking at the chromosphere and prominences at one definite place on the edge of the sun's disc, through an exceedingly narrow slit. He cannot see anything of their form or structure, but this is only because the slit is so very narrow. But if he widens the slit by means of the screw which regulates its aperture, the details of the chromo-

sphere and prominences at that particular portion of the sun's disc begin to appear; and when the slit is open enough, there is a minute picture, all in one color, of the particular region under observation. It was thus that Sir William Huggins discovered the possibility of seeing the shape and the changes of the chromosphere and its prominences, in full daylight

Changes in the prominences and their movements shown by the spectroscope

The chromosphere has several bright lines in its spectrum, and any one of these may be used in this way, so as to form an image of its shape and of its prominences and their movements. Thus, a picture may be obtained in a blue line of the spectrum, in a yellow line, and in a violet line But as might be expected from the ruddy color which the chromosphere presents at times of eclipse, the predominant element in its light is red; and it is therefore the red portion of the spectrum that is used for visual observations of the chromosphere. Red light, however, is photographically inactive, and only with very specially prepared plates can a picture be taken with this light. Hence, when the camera is put in train with the telescope and spectroscope so as to obtain photographic records of the chromosphere and the prominences, a bright line at the extreme violet end of the spectrum is used. This light, though almost invisible to the eye, has great photographic activity. By its means Professor Hale, first at the Yerkes Observatory and later at the Mount Wilson Solar Observatory, produced with the spectroheliograph, more fully described elsewhere (see page 2116), a wonderful series of photographs of the entire chromosphere with all the prominences which at the time it may happen to show. These photographs, which appear like a fine circle of irregular light on a black background, are of special value in the study of the rapid changes in the prominences.

These prominences, like the flames of some gigantic conflagration, often move with prodigious celerity, rising and falling, sweeping in terrific blasts this way and that.

How the spectroscope is used to measure the speed of flashing luminous gases

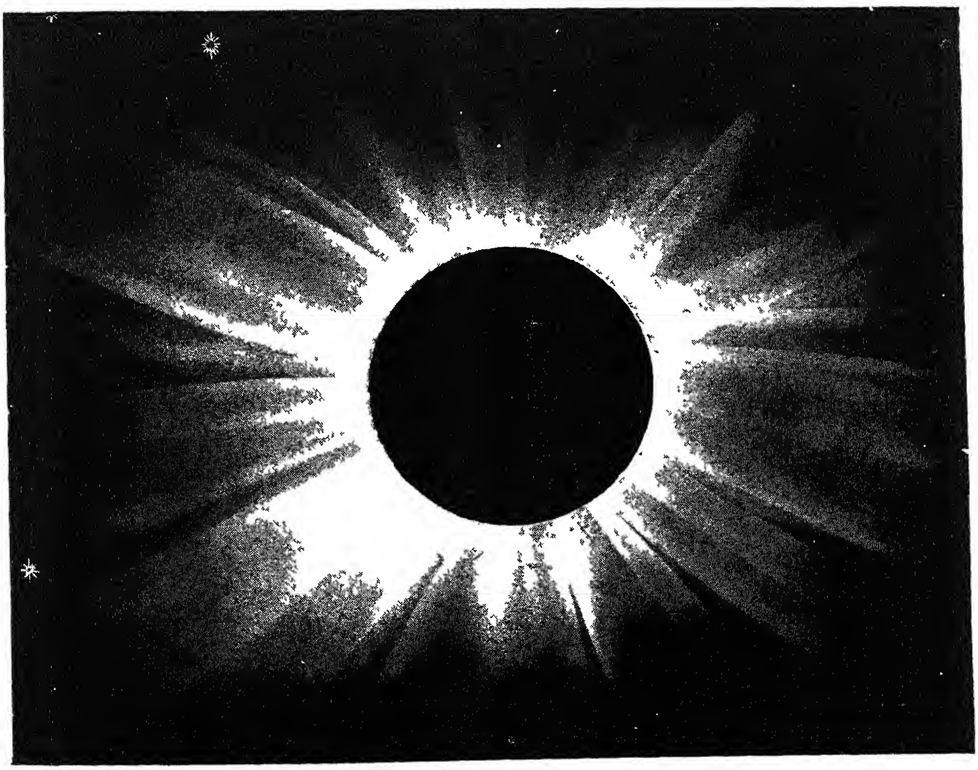
Here again, for the third time, the spectroscope shows the astonishing diversity of its powers. We have seen how an image of a portion of the chromosphere, and of the prominences upon it, is viewed through a widened slit of the spectroscope. Obviously, the movements which any prominence makes in the plane of that picture while it is being visually observed can be estimated easily enough. But how is it possible to estimate those movements which it makes towards or away from the observer? How can the speed of its motion in the line of sight be measured? When we watch the movements of any distant terrestrial object, it is easy enough to see how fast it is moving to right or left, or upward or downward, but it is often difficult to tell whether it is moving in the line of sight at all, and if the latter is true, whether the object is approaching or receding from the observer.

But in the case of a luminous body of gas moving at high speed, such as one of these prominences, the spectroscope can be made to give exactly that information It can show whether this body is approaching or receding from the observer, and can even indicate approximately its speed along the line of sight. If, for instance, the flame is approaching, the lines of its spectrum instead of falling on their accustomed places in the scale of the spectrum, are displaced somewhat toward the violet end of the scale. On the other hand, if it is receding, the lines which characterize it are displaced towards the red end of the spectrum; the more rapid the motion of the gas the greater is the displacement of the spectral line and hence the degree of this displacement can be used as a measure of the flame's velocity along the line of sight.

The explanation of this method of ascertaining the speed of the movement towards or away from the observer is simple enough. If the luminous gas be stationary, it sends out light of certain definite wave-lengths, showing themselves in certain definite bright lines of the spectrum.

Effects of approaching or receding light like approaching or receding sound

Considering the light that gives one of those bright lines, and for the moment neglecting the others, we find its line stands in that definite place on the scale of the spectrum, because its waves succeed one another at a definite frequency If the frequency with which its waves succeed one another be increased, its spectral line must move a little away from the red end, characterized by the slowest vibrations, and a little towards the violet end, characterized by the quickest vibrations. If, on the contrary, the frequency with which its waves succeed one another be diminished, the spectral line must move a little away from the violet and towards the red. But obviously, if the luminous gas which is the source of these vibrations should begin to rush away from the observer, its light-waves will reach the observer in less rapid succession than before, and the bright line they make in the spectrum will consequently shift towards the red. Similarly, if the flame begins to rush towards the observer, its light-waves will reach the observer in more rapid succession than if it were stationary, and its bright line will therefore be shifted towards the violet end of the spectrum The effect has been well compared to the change in pitch of a locomotive's whistle as it rushes past the listener on a station platform. The engine is making the same sound all the time, but the note is raised by its swift approach, and is lowered as it rapidly recedes. So, just as it passes the listener, the pitch of the sound falls through a considerable interval.



A DRAWING OF AN ECLIPSE, SHOWING THE CORONA AND PROMINENCES

This drawing represents an eclipse when sun-spots are at their maxima, and the prominences are consequently numerous The spots of bright light at the lower left hand of the disc peeping through the valleys between lunar mountains are known as "Bailey's Beads".

The prominences or protuberances of the chromosphere were first noticed as brilliant red, starry points of light on the edge of the moon, during the total eclipse of the sun

The prominences, seen momentarily in eclipse, made steadily apparent

Owing to the spectroscopic methods already described, their principal features have now been thoroughly ascertained. They are closely associated with those activities or disturbances of the sun which result in the production of sun-spots and faculæ. They are numerous in those years when sun-spots are at their maximum, and are few in number at the periods of minimum sun-spots. Moreover, both sun-spots and faculæ, but especially the latter, when seen at the edge of the sun's disc, are found to be closely accompanied by prominences.

Records show that the number of large prominences visible at one time round the edge of the sun varies from zero to twenty or thirty; but it must be remembered that those seen in profile at the circumference of the disc only form a very small proportion of those which must be simultaneously present over the whole surface of the sun. Although prominences occur in every region of the sun, from the equator to the poles, they are most numerous in the latitudes chiefly frequented by sun-spots.

Astonishing rapidity of motion attained by prominences and their parts

The prominences vary much in height, and sometimes reach prodigious elevations. A large proportion of them attain a height of from 20,000 to 30,000 miles, not many exceed 100,000 miles, but isolated examples have been recorded as attaining elevations of 200,000 miles, 300,000 miles, and even more. On October 7, 1880, Professor Young observed one that reached a height of 350,000 miles. The following account which he gave of it is interesting as showing the enormous rapidity with which these columns of flame are often formed. "When first seen, on the south-east limb of the sun, about 10.30 A.M., it was a 'horn', of ordinary appearance, some 40,000 miles in elevation, and attracted no special attention. When next seen, half an hour later, it had become very brilliant, and had doubled its height. During the next hour it stretched upwards until it reached the enormous altitude mentioned, breaking up into filaments that gradually faded away, until, by 12.30 P.M., there was nothing left. A telescopic examination of the sun's disc showed nothing to account for such an extraordinary outburst, except some small and not very brilliant faculæ. While it was extending upward most rapidly, a violent cyclonic motion was shown in the lower part by the displacement of the spectrum lines." The last remark refers to the movements of the incandescent gases along the line of sight, towards and away from the observer. The motion of prominences and of their parts often attains amazing velocity, a speed of over 200 miles a second having been ascertained.

The extraordinary variety of changing forms in the eruptive prominences

Two principal kinds of prominences are clearly distinguished from one another, and are known respectively as the quiescent and the eruptive. The quiescent kind are clouds of incandescent hydrogen, and have sometimes been seen to form spontaneously in the atmosphere in which they float, without having any contact with the chromosphere below. More often they are at the summit of one or more thin, irregular columns that expand as they rise from the chromosphere to form the widely floating clouds. The several cloud forms with which we are familiar in our earthly atmosphere are closely reproduced in these quiescent prominences. Their changes are slow, so that the same cloud may retain its form for several days. Their spectrum, showing principally hydrogen, though often mixed with magnesium and sodium, marks them as having a different origin from the other kind of prominences caused by violent eruptions and showing a spectrum bright with the lines of many metals.

These eruptive prominences, usually closely connected with sun-spots, assume an extraordinary variety of forms. Unlike the quiescent prominences, they rise, and change, and disappear with amazing speed. Professor Young described some of their appearances in graphic words:

"Sometimes they consist of pointed rays, diverging in all directions, like hedgehog spines; sometimes they look like flames; sometimes like sheaves of grain; sometimes like whirling waterspouts, capped with a great cloud; occasionally they present most exactly the appearance of jets of liquid fire, rising and falling in graceful parabolas; frequently they carry on their edges spirals like the volutes of an Ionic column; and continually they detach filaments which rise to a great elevation, gradually expanding and growing fainter as they ascend, until the eye loses them." They consist essentially of eruptions of vast masses of gas, driven off from the sun with enormous speed. The eruptive prominences are in general not so high as the quiescent kind, but, on the other hand, prominences of exceptional height are always of the eruptive kind.

The great difficulty of observing the sun's elusive corona

The corona, or "crown", was well known to the ancients, yet its nature is little understood even now. There are several reasons for this. In the first place, it is visible only at times of total eclipse, so that opportunities for its study are rare and very brief. If an astronomer were to make the examination of the corona the first aim of his life, and were to voyage over the world to see every total eclipse, and were fortunate enough to have clear skies for every one of his observations, after forty years of work he would have seen the corona for about an hour. Again, not many years have passed since the corona was proved beyond question to be part of the sun; it was formerly thought by many to be some transparent feature of the moon, illumined by the hidden sun. But perhaps the chief difficulty lies in the strangely elusive character of the corona itself. Two or more people with equally keen vision, equally well trained, and observing it from the same place, will see the corona quite differently and make quite different drawings of it. This difficulty is not overcome even by photography. Some impression of the various appearances of the corona may be gained from our illustrations.

Various forms assumed by the mysterious splendor of the corona

The forms this mysterious splendor assumes seem to be infinitely various. From round a coal-black moon, which at the moment of total eclipse shows visibly its spherical form, there extend outward in every direction threads and films, streamers and banners of light, brighter and more definite at their origin and becoming more faint and nebulous towards their outer extremities. Their direction is mainly but not exclusively radial, for brilliant shafts shoot off at a tangent to the sun, and some are curved like scimitars, or even hooks or loops, and others are shaped like leaves. Black rifts of darkness, which may also be curved, often cut the halo from center to periphery. The corona's beams extend outward to vast distances, sometimes attaining a length of many times the diameter of the sun's disc.

The light of the corona is generally described as pearly in color and appearance. The most various estimates have been formed of its illuminating power. Indeed, its extent, and therefore probably its radiance also, are much greater at some times than at others, depending upon the activity of the sun as shown in the sun-spots and prominences. Its inner parts are too bright for the eye if viewed with a telescope without the interposition of a tinted glass; and the evidence seems to show, on the whole, that the entire corona gives more light than the full moon. It reveals the landscape very clearly, though without color; objects whether near or far are seen distinctly, but somewhat as they are seen in sunlight through dark tinted glasses.

The spectrum of the corona has shown certain lines not found in the spectra of terrestrial elements, and hence a new element was proposed: *coronium*. However, recent investigations by J. Boyce and D. Menzel have indicated that the coronal lines may be due to oxygen in peculiar states of excitation high in the solar atmosphere. These states of excitation would be rare for terrestrial oxygen.

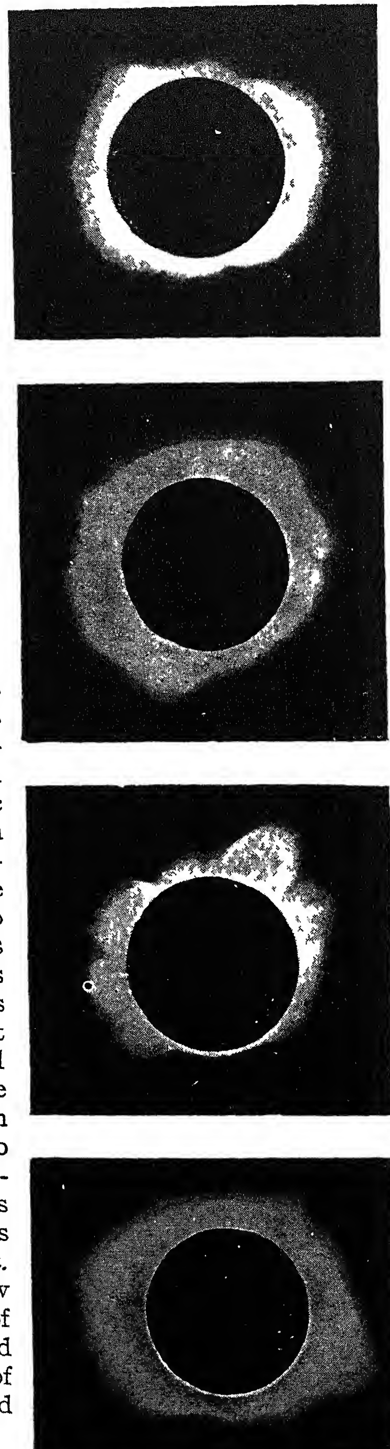
Besides certain doubtful bright lines, the coronal spectrum contains also the bright lines of hydrogen. Hydrogen is by far the lightest of all the chemical elements; its atomic weight is only 1.008. Under ordinary conditions it is a gas.

The corona consists, in part, of other elements which are not gaseous at all. There are three main evidences of this fact. In the first place, the bright lines of the coronal spectrum are given just as clearly by those rifts of darkness which were described above as existing in the corona, as they are given by the brilliant parts of the aureole. This shows that the brightness of the corona cannot depend upon the light which yields its characteristic bright-line spectrum. In the second place, in addition to that bright-line spectrum which is due to its gases, the corona throws also a faint continuous spectrum, which means that some of the light comes from solid or liquid particles. And in the third place, the light from the corona is found to have been partially polarized in such a way as proves that it consists partially of reflected light. Recent observations show that about 35 per cent of the light is polarized and that about two thirds of it is due to reflection and dispersion.

The corona consists, therefore, partly of an incandescent gaseous atmosphere, extending for a vast distance outward from the sun's surface, and partly of dust or fog or swarms of meteors. But there are almost certainly other elements also.

The wonderfully various arrangement of the shafts of light is not yet fully understood. The streamers are in general most strongly developed radially from those zones of the sun where sun-spots are most frequent: the individual rays, however, are not directly connected with the spots, but rather with the prominences. On the whole, the corona, though varying greatly in form, is in each case symmetrical about a line slightly inclined to the sun's axis of rotation. Recent evidence indicates that the disposition of the coronal arches is determined by magnetic influences and that the line of symmetry referred to is the sun's magnetic axis.

Our knowledge of the corona is continually advancing, but this magnificent solar appendage still presents a number of unsolved problems. A study of comets and the aurora may help to their solution. "It seems likely," wrote Professor Young, in 1881, "that the phenomena of comets' tails and the streamers of the aurora are phenomena of the same order; and though as yet the establishment of this relation would not amount to anything like an explanation of the corona, it would be a step toward it."



THE CHANGING CORONA OF THE SUN AS SEEN AT VARIOUS DATES

ROMANCE OF THE SEA-BEDS

Does the Great Pacific Ocean Fill a Huge Rent from Which the Moon Was Torn?

THE DARK, UNFATHOMED CAVES OF OCEAN

WHATEVER the source of the water on the face of our planet, there can be no doubt that the seas were originally condensed from steam. The question remains: how are we to explain the present disposition of land and water? How came there to be the great chasms and cauldrons that hold the great seas? How has it come about that there is dry land at all? It seems natural to assume that where there is sea there must be land; it seems natural to assume that the present proportions of land and water came about as a matter of course; but both assumptions are quite wrong. There might very well have been a sea covering the whole surface of the world—there is plenty of water for the purpose; and a very little rearrangement of the surface markings of the earth would vastly alter the distribution of its land and water.

The mean height of the land is 2800 feet; the mean depth of the sea is 12,450 feet and the surface area of the sea is more than two and a half times the surface area of the land—about 139,440,000 square miles of water to 57,510,000 square miles of land. The Pacific Ocean is the largest ocean with an area of 68,634,000 square miles as compared with the Atlantic's 41,322,000 square miles. Asia is the largest of the continents with a surface area of 17,000,000 square miles. North America has a mere 8,000,000.

Even a comparatively small rise or fall of the sea-level would have startling geographical consequences. A drop of 600 feet in the level of the sea would unite Britain and France; it would also unite Asia and America by the Behring Straits, and attach Ceylon to India, and Papua and Tasmania to Australia, and would probably render it possible to travel dryshod from Sydney to Pekin and from Pekin to Klondike. Altogether it would lay bare 10,000,000 new square miles of dry land. On the other hand, a rise in sea-level of 2000 feet would submerge the greater part of the dry land. It is just the depth and size of the great ocean beds that have chiefly decided the shape and size of the continents From them have come the denuding waters, and carried to them, the ruins of the lands wherein they ran and delved.

Now, what delved or indented the ocean beds? We have seen that the crust of the earth has been rising and falling in its continental areas in rather an amazing way; we have seen that æons ago a sea flowed where now the peaks of the Himalayas soar heavenward; but we have also seen that it is probable that the abyssal depths of the great seas have endured for countless ages. What made the bed of the Pacific, and what made the bed of the Atlantic Ocean? By what natural agency were they made, and why are they so permanent and their shores so changing?

To these great questions there are many answers, and yet none that has met with unqualified acceptance. We have already mentioned the theory that the Pacific Ocean bed was a scar left in the earth's side when the moon was wrenched from it.

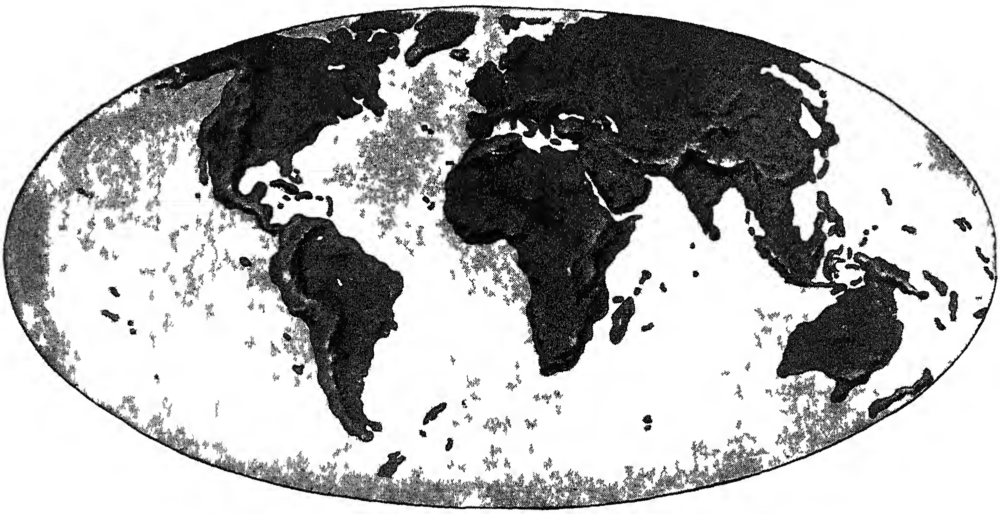
This is certainly a curious theory, one that appeals to the imagination, but it is not proven; and even if one or two holes were made in this way in the crust of the earth, it is quite likely that they did not persist.

At this time the earth was in a wholly soft plastic condition, and very probably under the influence of gravitation and rotation the hole or holes would fill up, and the whirling mass would again acquire the pear shape it probably had at the time of its disruption In this event, the original sea would condense round the neck of the pear Through the sea the point of the pear would project as a large island, while the broad end of the pear would form a great continuous continent

The original sea is still represented by the Pacific Ocean, but the original great continent is now broken up by the Atlantic and Mediterranean Sea which were subsidences in the primitive crust We have already described the changes in the contours of seas and continents which took place during the geological eras, but we may now briefly recapitulate the distribution of land and water in the Mesozoic Period

At that period North America, Greenland, Iceland and northern Europe formed a continuous continent, connected by a narrow neck of land with the older continent of Gondwana, which included Africa, South America, Arabia southern India and Australia Most of southern Europe was then covered by the ancient Tethys Sea which not only divided northern Europe from Africa, but also sent an arm north, dividing Europe from Asia, and an arm west over the position of the present Himalayas, separating the Indian and Malay peninsulas (then incorporated in Gondwana) from the rest of Asia North-eastern Asia thus cut off from India, Europe and Africa formed a huge island-continent known as Angara The Atlantic at that time was represented by an immense inland lake (Laramie) which communicated with the Pacific by a narrow strait where the isthmus of Suez now is

That was the land and sea distribution in Mesozoic times and a glance at the map will show that great changes have taken place since then Australia is now separated from Africa by the Indian Ocean



THE LAND THAT WOULD BE LEFT IF THE SEA SANK 600 FEET

Africa is separated from South America by the southern Atlantic Between Europe and America now stretches the stormy north Atlantic While from the ancient Tethys Sea has arisen Asia Minor and the Himalaya mountains

Leaving this interesting question of the *origin* of the great seas and sea-beds, let us now look at the former as they now are

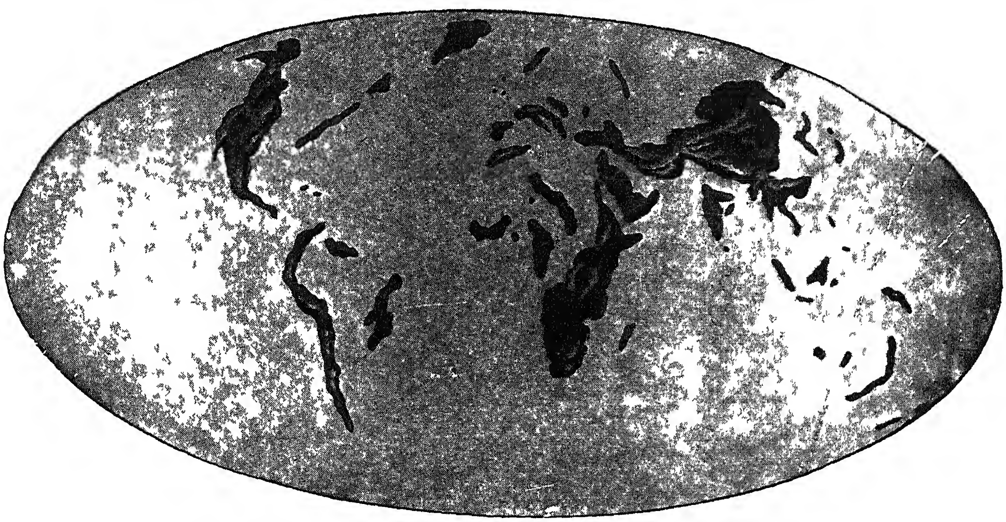
That greatest of all seas, the Pacific Ocean, with its area of 68,634,000 square miles—has an area much greater than all the dry land of the globe It contains many islands, but there are parts of it 2500 miles from the nearest continent. It is a deeper sea than the Atlantic, the greater portion of it is more than 14,000 feet deep, and there are parts much deeper

Off the coast of Peru there is a narrow trench over 28,000 feet deep Off the east coast of Japan there is an area larger than New Zealand, known as the Tuscarora Deep over 28,000 feet deep and in one place near the Kurile Islands a depth of 27,930 feet has been recorded Off the Island of Mindanao, in the Philippines Group, a sounding of 35 400 feet, which indicates a depth of more than six miles, is reported by the U S Geological Survey. On the other hand, the Behring Straits are only 300 feet deep, and the sea between Asia and the Philippines and between the Philippines and the Australasian islands is rarely more than 600 feet deep

The Atlantic Ocean includes in its vast area of 41,322,000 square miles its arms the Arctic Ocean and Mediterranean Sea. Truly the ocean of rivers, into it directly or indirectly, flow almost all the big rivers of the world — the Amazon, the Mississippi, the Orinoco, the La Plata, the Uruguay the Parana, the Congo the Niger, the Nile, the St Lawrence, the Danube, the Rhine, the Rhone, etc Though not so deep as the Pacific, it is, as a whole, deep, and in many places exceeds a depth of 18,000 feet It is divided into two troughs, an eastern and a western, by a submarine plateau known as the Dolphin Ridge, which runs north and south, and over which there is rarely more than 12,000 feet of water. From it rise Iceland, the Faroes, the Shetland Islands, the Azores Ascension Island and Tristan d'Acunha The greatest sounding in the Atlantic Ocean (30,246 feet) was obtained about seventy miles north of Porto Rico

The Indian Ocean is a little more than half the size of the Atlantic and reaches a depth of 22,968 feet Its average depth is 15 000 feet and the deepest parts are between Java and northwestern Australia

The Mediterranean is properly an arm of the Atlantic, with which it communicates by the Straits of Gibraltar Comparatively speaking, it is shallow sea Were it lowered even 600 feet it would cause great international and geographical consequences, for the Dardanelles and the Bosphorus would become dry land, the Adriatic Sea would be almost entirely abolished, Majorca would join Minorca, Sardinia, Corsica, and Malta, Sicily Were it lowered 1200 feet the Straits of Gibraltar would become an isthmus and were it lowered 1460 feet it would be divided into eastern and western landlocked seas by an arm of land stretching from Malta to Africa The Mediterranean is deepest towards its eastern end, and attains a depth of 14 450 feet.



THE LAND THAT WOULD BE LEFT IF THE SEA ROSE 2000 FEET

Besides these great open seas there are various seas quite inclosed by land — for example, the Caspian Sea, the Sea of Aral and the great African lakes.

The Caspian Sea is 18,000 feet deep, enough to submerge Mount St. Elias, and it covers a space nearly three times the area of New England. Both it and the Sea of Aral are remnants of the ancient Mediterranean or Tethys Sea.

Though the great African lakes are now so far from the sea, there seems no doubt that they are oceanic in origin, for they are still tenanted by marine animals. These inland seas have been produced, of course, by the rising of the land, and not by the sinking of the sea. The Caspian and the Sea of Aral became landlocked in the process of that tremendous upheaval of ocean bed which culminated in the Himalayas.

When we compare the contour of the floor of the sea with that of the dry land we find resemblances and differences. On the whole, the former is more undulating and has more gentle gradients than the latter, but, on the other hand, its mountains, often appearing above its surface as islands, rise more abruptly. So gradual are the gradients that, so far as hills go, an automobile could be driven all the way from Ireland to Newfoundland.

What walking on the bed of the ocean would be like

Professor Bonney contrasts sea floor and dry land thus: "If a model were constructed to exhibit the contours of the land surface and of the ocean bed, and if a cast were taken of this in some flexible material, which was then turned so as to make another globe, it would be found that on the former model a series of ridges, comparatively narrow and steep, formed an interrupted network, in the wide interstices of which the surface shelved down into basins of variable depth; while on the other a series of gentle and undulating plateaus were parted by narrow furrows, the beds of which were broken by somewhat deeper pits, corresponding, of course, with the mountain peaks of our globe."

Professors Chamberlin and Salisbury remark that "If the water were drawn off the ocean's bed so that it could be seen as land is, the most impressive feature would be its monotony".

We have seen that if the Atlantic Ocean were evaporated down to a certain extent it would be divided by the Dolphin Ridge into an eastern and western basin; and we have seen that similarly in the case of the Mediterranean, eastern and western basins would be separated. This is typical of the nature of the ocean bed: it consists of basin-like undulations or depressions, and, *pari passu*, with a diminution of water the sea would be divided and subdivided into lesser seas in lesser-sized basins.

How the floor of the ocean is creased and lined

Here and there in the ocean bed occur deep channels, sometimes over a thousand feet deeper than the adjacent ocean floor. These are known as "swatches", and are supposed to represent ancient river valleys that have been submerged by the sea.

Such, then, is the general depth and contour of the present-day ocean beds; and it is pretty certain that while the marginal boundaries of the basins have known many ups and downs within geological times, the bottoms of the deep central seas have remained down for countless ages.

Let us now look at the geological characters of the floor of the ocean — "the great, gray, level plains of ooze where the shell-burred cables creep".

Up till the middle of last century nothing was known of the nature of the deposits on the ocean floor, but the necessity of surveying the floor of the ocean with a view to laying cables stimulated research and numerous expeditions, such as the *Challenger* expedition in 1872–1876, have given us a wealth of information with regard to the crust of the earth under the sea.

It is possible to procure samples of mud and ooze from the sea floor by means of a sounding lead slightly hollowed out at its lower end, and greased with tallow. When this lead strikes sea bottom, mud adheres to it and can be hauled up for examination, but scientific expeditions use more elaborate instruments for the purpose.

The scientists of the *Challenger* expedition, which did so much to increase our knowledge of the ocean beds, divided marine deposits as follows:

MARINE DEPOSITS

1. Deep-Sea Deposits (beyond 100 fathoms)	Red Clay	I. Pelagic Deposits formed in deep water remote from land
	Radiolarian Ooze	
	Diatom Ooze	
	Globigerina Ooze	
	Pteropod Ooze	
	Blue Mud	II. Terrigenous Deposits formed in deep and shallow water close to land masses
	Red Mud	
	Green Mud	
	Volcanic Mud	
	Coral Mud	
2 Shallow-Water Deposits (in less than 100 fathoms), sands, gravels, muds, etc.		
3. Littoral Deposits (between high and low water marks), sands, gravels, muds, etc.		

(*a*) *Littoral Zone.* The zone of deposits lying between high and low water-mark has the well-known characters of the ordinary beach. It consists chiefly of sand, pebbles and boulders derived from the land by the action of the tides, and of the rivers flowing into the sea. As a rule, the coarser material is flung highest up on the beach, and towards low water mark the detritus grows progressively finer. The more sheltered the shore, too, the finer will the material of the beach be. Occasionally organic calcareous matter and fragments of shells are cemented together into rocks; and in some cases, especially on the shores of Arctic seas, there are huge accumulations of driftwood

The coasts of the world are about one hundred and twenty-five thousand miles in length, and the whole tidal area amounts to many thousands of square miles.

(*b*) *Shallow-Water Zone.* The sediment deposited in water less than a hundred fathoms deep is of much the same nature as the sediment of beaches. On the whole, it is finer, but it varies between mud, sand, and gravel.

(*c*) *Deep-Sea Zone.* The deep-sea zone, as is seen in the table we have given, is partly formed from land debris or muds, and partly of the so-called oozes.

We shall first describe the muds. The distance from land to which land mud can be carried varies considerably. As a rule, it is all deposited within two hundred, or, at the outside, two hundred and fifty miles from land. But pumice-stone, which is light and porous, may drift a long way before it sinks, and large, rapid, muddy rivers flowing into the sea can carry mud for a great distance. Congo mud, for instance, has been found 600 miles, and the mud of the Indus and Ganges 1000 miles, from the shores that produced it Further, of course, volcanic dust may be carried by wind round and round the world before it sinks as mud to the bottom of the sea, and storms may carry ordinary dust for almost incredible distances. A certain quantity of mud and stones may also be carried by icebergs, and deposited at points a remarkably long way from the land of their origin.

The muds that coat the untrodden bottom of the ocean bed

Almost all mud thus composed of detritus of the land contains little particles of minerals, such as quartz, mica, hornblende; and occasionally there are larger or smaller quantities of terrestrial vegetation, such as leaves, fruits, twigs, seeds. All earth-derived muds become dust when dried.

Now let us look at some of the specially named terrigenous muds.

1. *Blue Mud.* Blue mud is formed by powdered crystalline rocks mixed with decomposing organic matter and sulphide of iron. When iron is present in the form of ferric oxide, the mud often assumes a brown or red hue; and the surface layer of blue mud is often red or brown for this reason. Blue mud is often mud carried into the sea by rivers, and hence often contains terrestrial vegetable and animal matter. Usually, too, in such mud there is a certain amount of carbonate of lime, derived from shell-fish in the water.

2. *Red Mud.* Red mud is derived from the blue mud by the oxidation of the organically held ferrous oxide.

3 *Green Mud.* Green mud is only a variety of blue mud and gets its color from a green mineral called glauconite, which contains the oxides of iron, potassium aluminum and silicon.

4. *Coral muds* and *volcanic muds* require no special mention; they are produced from the debris of coral and volcanic rock respectively.

The oozes that drop down from the upper shell-laden waters

We now come to the very interesting subject of the oozes. The oozes are not formed from land materials washed into the sea, but mainly from the calcareous and siliceous skeletons of deep-sea organisms. These organisms, often microscopic, have the power of collecting lime and silica from the sea-water and of building shells therewith; and when the organisms die the shells fall down and accumulate on the ocean floor.

1. *The Pteropod Ooze.* The pteropod ooze consists chiefly of the shells of pteropods and gastropods — species of shell-fish which live at the surface of the sea in great shoals. It is found chiefly on the submarine ridges of tropical seas, and never occurs at greater depths than 1000 fathoms. The reason of this limitation in depth seems to be that the delicate shells are gradually dissolved as they fall through the sea-water; and by the time they reach greater depths than 1000 fathoms have dissolved altogether. Pteropod ooze is known to occur over an area of 257,000 square miles.

2. *The Globigerina Ooze.* The globigerina ooze consists mainly of the shells of certain minute shelled organisms known as *Globigerina bulloides*, which belong to the order Foraminifera. When these shells are examined under the microscope, they are seen to be composed of several intercommunicating chambers pierced with numerous apertures. When the organism is alive, its soft, jelly-like body occupies the chambers, and thread-like arms pass through the apertures and wave about in the water. After death, as the dead organism falls through the water, the body is dissolved and only the tiny shell reaches the sea floor.

The shells that in the ages lay down at the bottom of the sea future hills of chalk

Where the sea is deeper than 2000 fathoms, not only the body of the organism but also the shell is dissolved, and so globigerina ooze is seldom found in seas deeper than 2500 fathoms.

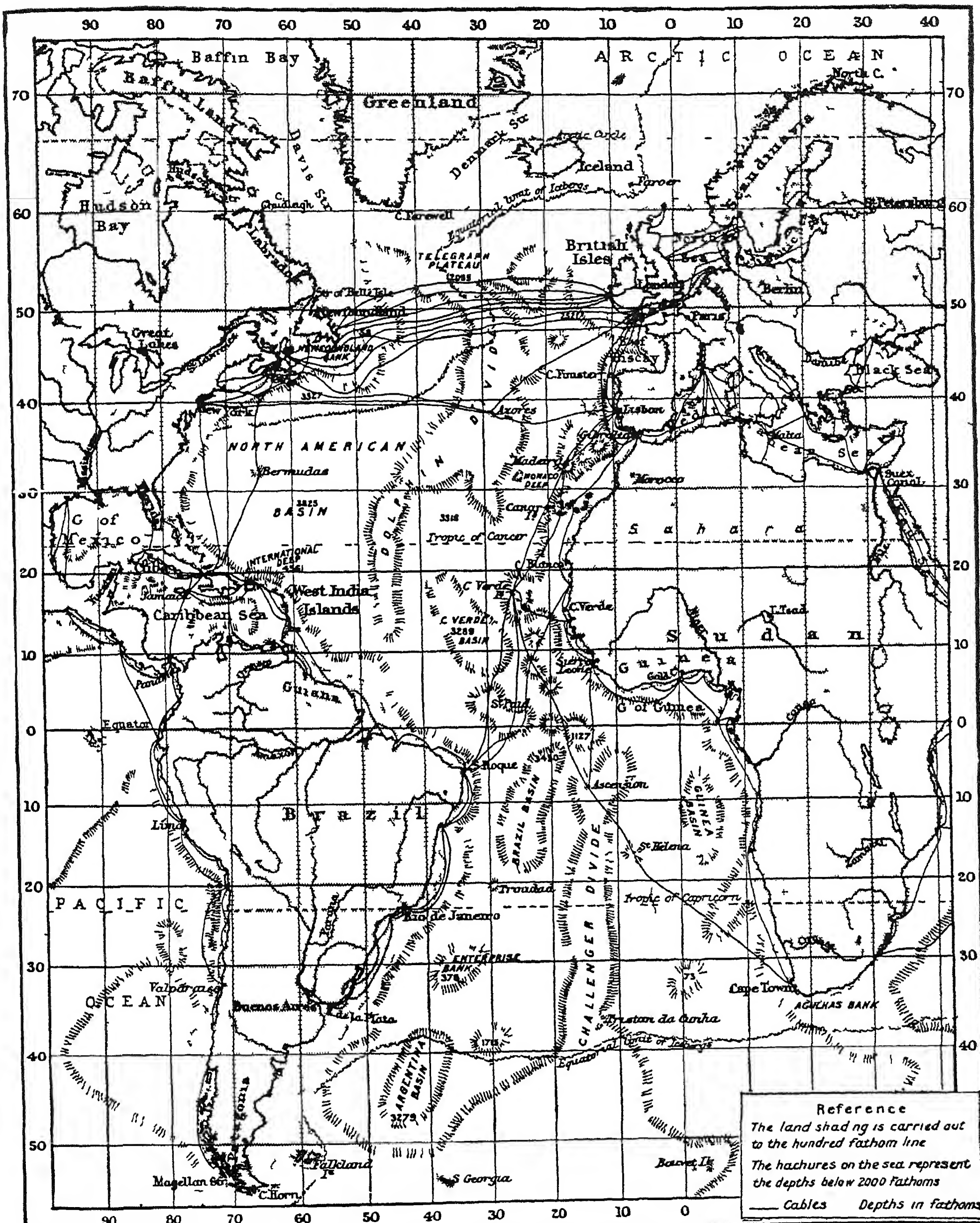
Out of 118 samples of globigerina ooze obtained by the *Challenger* expedition 13 came from depths of 1000 to 1500 fathoms 84 from depths of 1500 to 2500 fathoms and only 16 from depths greater than 2500 fathoms.

In appearance the globigerina ooze is a fine, creamy, pinkish or grayish mud. When dried, it becomes a chalk-like substance which may be used like chalk to write with. It is really essentially the same as chalk, consisting mainly of carbonate of lime, and effervescing when treated with acid. It is estimated that no less than 47,752,500 square miles are covered with it. It is the characteristic deposit of the Atlantic and covers an area of 17,000,000 square miles, while in the great Pacific it covers but 11,500,000. Yet it requires about 10,000 globigerina shells to cover one square inch.

All over the ocean, except in inclosed seas and cold arctic currents, this ooze is forming. All over the ocean floats a colossal cloud of these delicate, shell-creatures, and downwards from the cloud streams a rain of the dead. "A never-ceasing rain of dead shells, light as the dust which drops unfelt from the atmosphere, patters down silently and incessantly on the ocean floor." Slowly and gradually does the ooze accumulate. On the Atlantic cables it has been found to collect only at the rate of ten inches in a century. Yet the rain goes on, not for centuries, but for æons, and in time inches grow feet, and feet yards. Even if the Atlantic and Pacific oceans have been raining globigerine for only four hundred thousand years, each would have collected enough ooze to bury Vesuvius.

The geology of the sea bottom the geography of the future

How deep was the calcareous ooze in the bottom of the ancient seas testify the chalk cliffs and chalk mountains — the Needles, Mount Sinai, Mount Lebanon. The chalk cliffs of England were formed of the ooze of an ancient sea that millions of years ago flowed over the present site of the British Isles, and it must have been about 1500 feet thick. In other places it may have reached a depth of no less than 5000 feet.

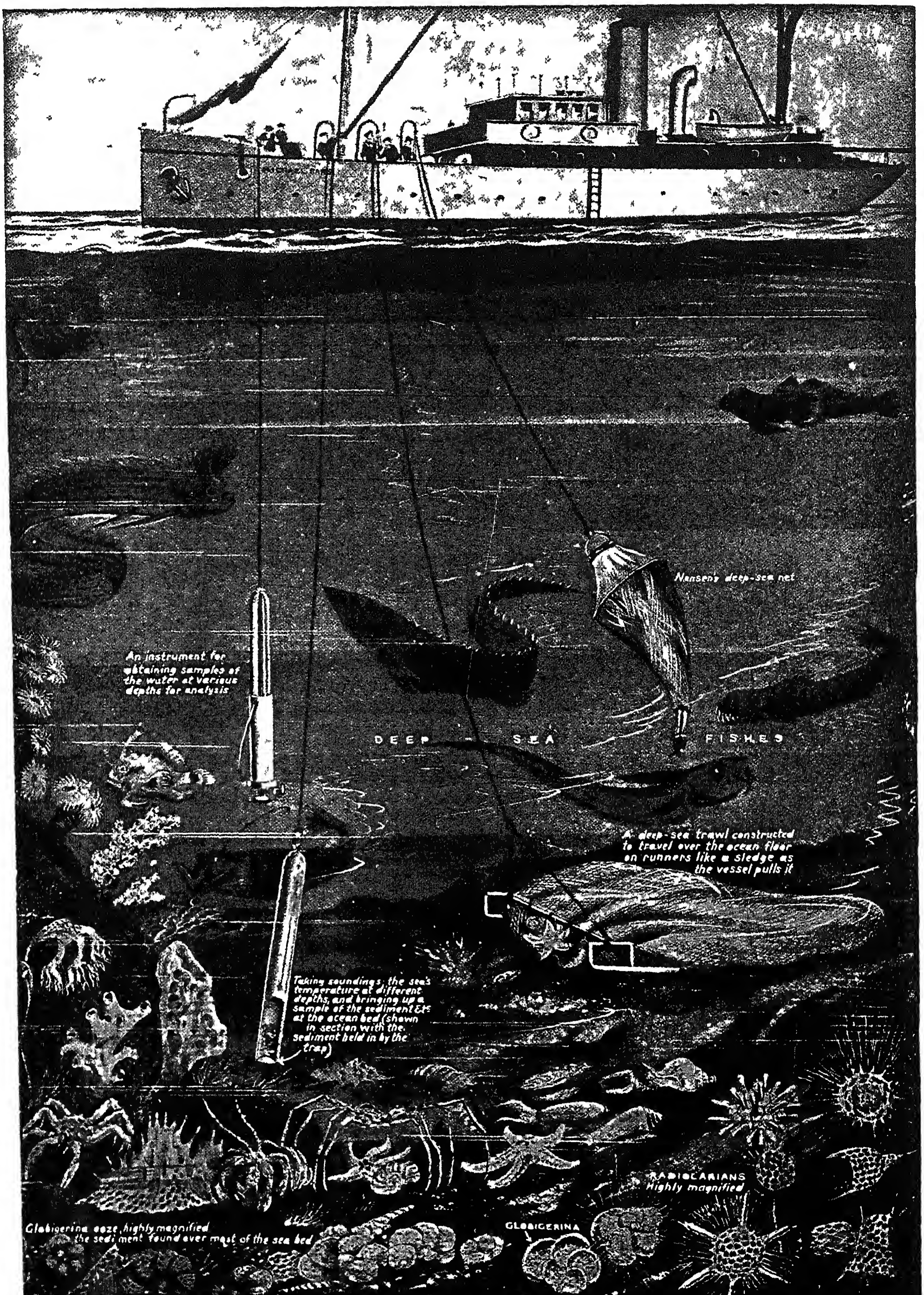


THE ATLANTIC OCEAN, SHOWING THE RELATIVE DEPTHS

However deep the present-day deposits of globigerina ooze may be, they are pregnant with great possibilities, for they are the stuff whereof future islands and continents and mountains may be made One day there may be a mountainous resurrection of all these dead globigerines. Down in the depths of the sea nature may be working out her plans

Mixed with globigerina ooze are multitudes of microscopic little calcareous discs called "coccoliths", which are sometimes massed together into spheroidal bodies which are called "coccospheres" These are usually supposed to be algæ or the spore-cases of algæ Other calcareous bodies known as "rhabdoliths" and "rhabdospheres" also occur

IN THE DEPTHS OF THE ATLANTIC OCEAN



This picture-diagram shows, in an exaggerated manner for the sake of clearness, the methods by which scientists explore the depths of the oceans and bring up various forms of life and deposits.

3 *Diatom Ooze* is an ooze formed principally of the siliceous skeletons of the microscopic little vegetables known as diatoms Siliceous shells are not dissolved as they pass through water, and hence they occur at all depths Diatom ooze occurs chiefly in the antarctic, where "at an average depth of about 2000 fathoms there is a wide band of soft, white ooze covering the sea-bottom between the parallel of 40° S, and extending to the antarctic circle and completely surrounding the southern hemisphere This band has an area of over ten millions of square miles"

4 *Radiolarian Ooze* Diatom ooze, as we have said consists mainly of the siliceous shells of minute *plants* Radiolarian ooze, on the other hand, consists chiefly of the siliceous shells of minute animals These minute creatures have a very wide distribution, and in their siliceous remains accumulate as a deep-sea deposit in various parts of the sea

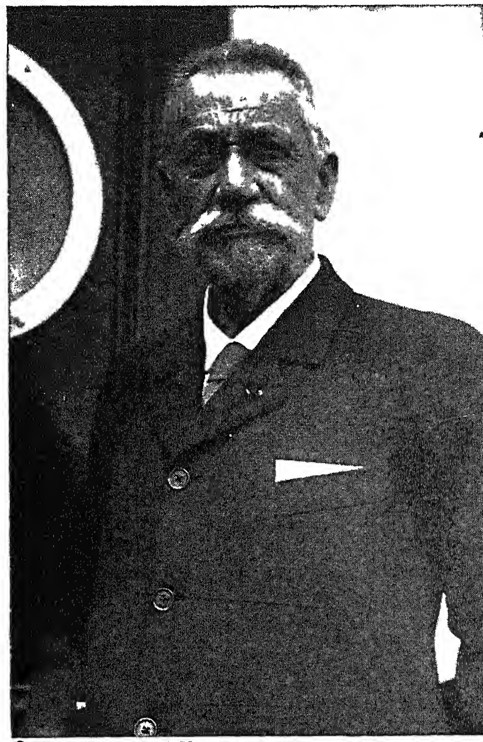
Teeth that are undissolved when all other animal substances have disappeared

5 *Red Clay* Though red clay may be considered among the oozes, it differs from the oozes in the important particular that it is mainly inorganic, and contains hardly any organic remains It is found only at great depths, and at a great distance from land, but it is the most widely distributed of all the sea deposits, covering an area of over 51,000,000 square miles, including more than half the area of the Pacific Ocean

Mineralogically, red clay consists mainly of volcanic material in a pulverized condition, together with meteoric dust and dust from deserts Its red or brown color is caused by the formation of ferric oxide and manganese peroxide in the process of the decomposition of the volcanic material Manganese nodules about the size and shape of large potatoes lie pretty plentifully upon its surface In the center of these nodules, acting as a nucleus, is often found some hard substance, such as a piece of pumice-stone or a shark's tooth Specially characteristic of red clay are the teeth of sharks and the ear-bones of whales

The old, old story of the world's past hidden in the slowly laid floor of the sea

No other bones are found all others are quickly dissolved under the conditions existing in these abysmal depths, and these alone survive because of their excessive hardness The sharks' teeth belong to species that must have been extinct for long ages



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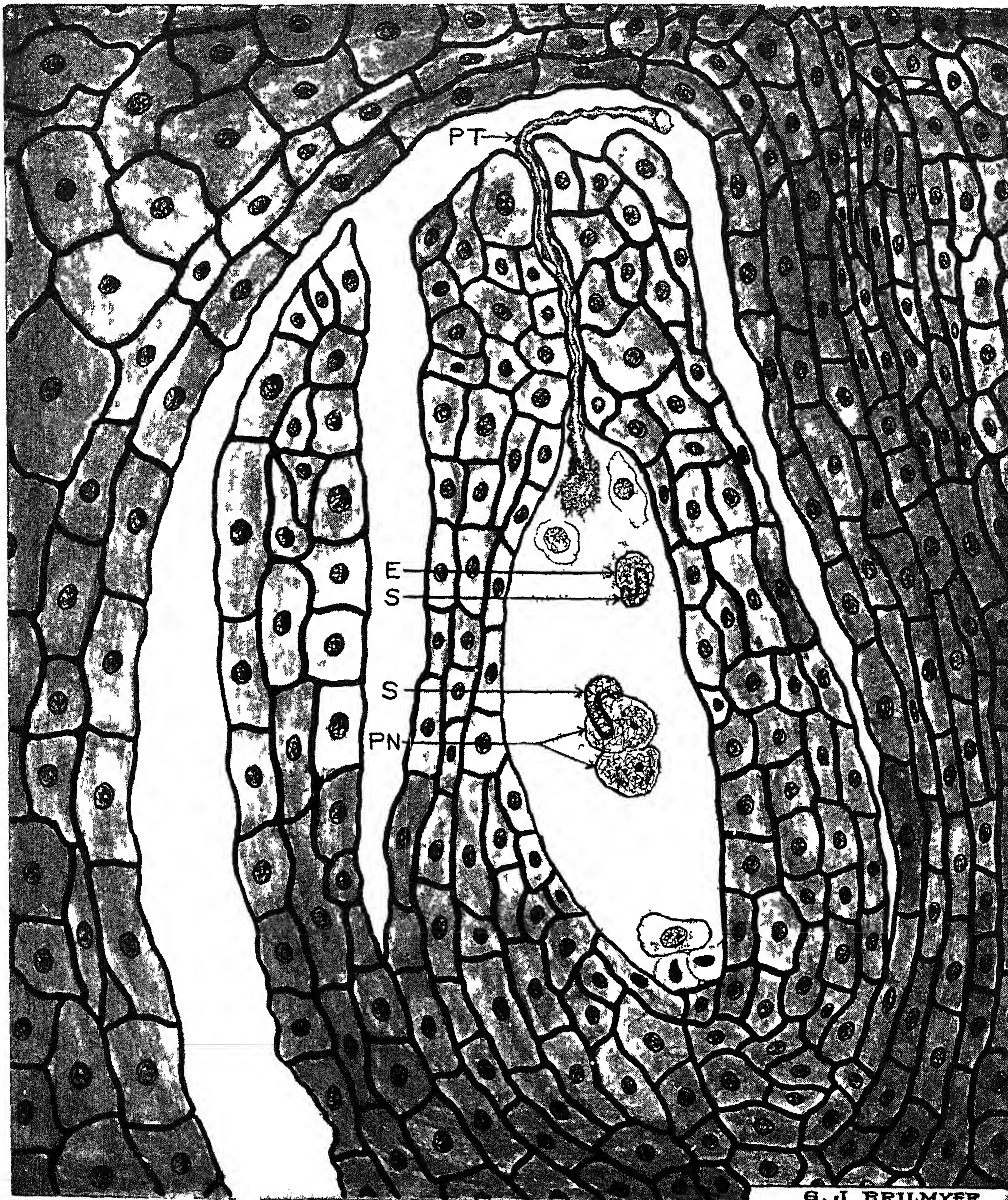
A GREAT OCEANOGRAPHER

The late Albert Honoré Charles Prince of Monaco (1848–1922) who spent his gains from the Monte Carlo gambling concession in his principality for scientific voyages to investigate deep sea life ocean beds and currents and the mapping of the oceans

Very strange it is to think that the bottoms of the deepest seas are plastered over with the dust of volcanoes and shooting-stars, and sprinkled with the teeth of extinct sharks Part of the volcanic debris may have come from submarine volcanoes, but the greater part is probably carried by the wind from volcanoes on the dry land This red clay sediment must be formed exceedingly slowly, otherwise the teeth of the extinct species of sharks and ear-bones of extinct species of whales must have been buried out of reach long ago

WHERE THE LILY'S SEED IS DEVELOPED



SECTION OF OVULE OF THE CORAL LILY AT THE TIME OF FERTILIZATION

This longitudinal section of the ovule of the coral lily shows within the ovule the so called "embryo sac" (female gametophyte), consisting of a mass of cytoplasm within which, at this stage, are eight nuclei, one of which (E) is the female gamete or egg The pollen tube (PT), which developed from a pollen grain that germinated on the stigma of the flower, has grown down into the ovule and has discharged its contents into the embryo sac Within this pollen tube (male gametophyte) two male gametes or sperm nuclei were produced One of these sperms (S) is seen fusing with the egg (E) to form a single cell, the fertilized egg, which will give rise to the embryo lily plant that is present in the mature seed The second sperm (S) is fusing with the two "polar nuclei" (PN) of the embryo sac to form a single cell from which arise the cells of the endosperm tissue, which surrounds and nourishes the developing embryo and also stores up food in the mature seed for use of the little plant when it sprouts and is establishing itself in the soil to outdo Solomon in all his glory when it comes to flower.

THE GERM-PLASM THEORY

How Far Life, Passed on from Generation to Generation, Belongs to the Race, or is Modified by the Individual

THE STUDY OF HEREDITY BY WEISMANN

THOUGH Francis Galton was the first to cast doubt upon the generally accepted view that characters due to functional modifications of the body of the parent are transmitted to the offspring, yet it is to a German contemporary of Galton's, somewhat his junior, that we owe the evidence and the ideas upon which the modern study of heredity is based This illustrious thinker was August Weismann who born in Frankfort in 1834, died in 1914 From 1863 to the time of his retirement in 1912 he was identified with the University of Freiberg, where he was professor of geology from 1871 His great book dedicated to the memory of Charles Darwin, was published in 1893 when the author was approaching his fiftieth year — which was Darwin's age when the "Origin of Species" was published — and it was the fruit of ten years' continuous study of our problem, added to the biological work of many years before Like Darwin's book, therefore, it is no hasty or immature production but represents the long and exhaustively considered verdict of a master, after full reflection and repeated resort to nature in confirmation of his views

In this respect Weismann's theory markedly contrasts with Darwin's own theory of heredity, called "pangenesis", which was based on no evidence at all, and the younger thinker's theory is further contrasted because it is the exact opposite of Darwin's, which we have already dealt with in this section Here, indeed, are Weismann's own words, in the modest and dignified preface to his book, of which the full title is "The Germ-Plasm A Theory of Heredity"

Weismann says "The pangenesis' of Darwin seemed to me to be far too independent of facts, and now I am of the opinion that the very hypothesis from which it derives its name is untenable There is now scarcely any doubt that the entire conception of the production of the 'gemmules' by the body-cells, their separation from the latter, and their 'circulation', is in reality wholly imaginary In this regard I am still quite as much opposed to Darwin's views as formerly, for I believe that all parts of the body do not contribute to produce a germ from which the new individual arises but that on the contrary, the offspring owes its origin to a peculiar substance of extremely complicated structure the germ-plasm' This substance can never be formed anew it can only grow, multiply and be transmitted from one generation to another My theory might therefore well be denominated 'blastogenesis' — or origin from a germ-plasm, in contradistinction to Darwin's theory of 'pangenesis', or origin from all parts of the *body* "

The theory of Darwin, that the germinal material is formed from all parts of the parental body, was a very useful and natural one in its time But, as Weismann says, when Darwin put forward his suggestion, "it was not possible to found any theory of heredity on the only sound basis — that of a knowledge of the most minute cell-structure" It was Weismann's work with the microscope that led him to substitute the idea of a part of the parental body separate from the first, in the body but not of it, which he specified by the term " germ-plasm "

First stated in the year 1883, this theory now comes to be considered by us four decades later. Meanwhile, the work of Mendel has been rediscovered, and his followers have supplemented and modified the views of Weismann by their own method of experimental breeding. But the method which studies the germinal material with the microscope remains and will always remain. We now have to summarize and pass revised judgment upon the work which definitely reversed our ideas of the relation between the body and the germinal material; we must note the conclusions which follow from Weismann's theory of heredity; and we must carefully correct an all but universal misunderstanding of his theory, which he himself sought to make inexcusable.

The microscope established once and for all the fact that the hereditary material consists of cells, and it soon began to be suspected that the nuclei of these germ-cells were their essential part. That we now hold to be established, though the most recent writer on the subject has suggested that perhaps the body of the germ-cells, the mere protoplasm outside the nucleus, may be also concerned in the transmission of characters. However that may be, the supreme place of the nuclei is unquestionable. Weismann early fixed upon the nuclei of the germ-cells, produced respectively by male and by female bodies, as constituting essentially what he called the "germ-plasm".

The invention of the "germ-plasm" by Weismann as a speculative necessity

By the germ-plasm he meant a something of which he felt bound to assume the existence, when he looked at the facts of heredity, "a special organized and living *hereditary substance*, which in all multicellular organisms, unlike the substance composing the perishable body of the individual, is transmitted from generation to generation. This is the theory of the continuity of the germ-plasm".

This germ-plasm, we observe, began as a speculative necessity. There must be such a thing, Weismann argued, if we did not grant the theory of Darwin that the body improvised its germinal material, so to speak, from and for itself. That theory could not be held; and the only alternative was this of a special hereditary substance, the germ-plasm, essentially continuous from generation to generation, not subject to natural death, like the bodies which housed and transmitted it, and therefore potentially immortal. And, as we have seen, the next step was to give this almost mystical entity, already named, a local habitation in the nuclei of those living cells which the microscope identified as the germinal material that leaves parental bodies and becomes the offspring.

So long as we deal with species of animals or plants which have only one sex, or with cases where, though the species exhibits both sexes, the females can reproduce alone, no difficulty arises. But wherever we have bi-sexual reproduction, with the union of two germ-plasms, there must be, Weismann argued, a "reduction of the germ-plasm", in each case, so that the two germ-plasms, each essentially halved before union, may unite to form a whole, for the formation of the new individual.

The theory of reduction of the germ-plasm to half its germinal material

This theory of the reduction of the germ-plasm was almost as daring as those from which it sprang, the theory of any such thing as the germ-plasm at all, and the theory of its continuity and potential immortality from generation to generation. Few theorists, however, have been justified by subsequently ascertained facts as has Weismann. He asserted a "reduction of the germ-plasm", and located the germ-plasm in the nuclei of the germ-cells. Yet when we look at a germ-cell, male or female, of any species of animal or plant, it seems to be quite entire, not at all one-sided, or like the split half of a cell. It was a very daring notion that each germ-cell, though visibly complete, yet contained only half of the germinal material proper to the species it belonged to, and that somehow, in the formation of that germ-cell, the other half of the germinal material had been lost.

The justification of Weismann's theories by subsequently ascertained facts

Yet, as we already know, exact experiment and microscopic observation justified this remarkable thinker. When the nuclei of germ-cells were examined, and especially when the processes leading up to the formation of the ripe or mature or final germ-cells were observed, a "reducing division", as Weismann called it, was demonstrated, in which one-half of the nuclear material was removed or lost, so that each ripe germ-cell, though entire and complete as a cell, did yet afford only one-half of its essential contents.

A further idea forces itself upon us when, with this idea of the germ-plasm in our minds, we contemplate the various species of animals and plants. According to Weismann — and we are now all agreed that he was right — the differences between a sheep and a dog, for instance, must be due to the fact that the body of the sheep is developed from sheep germ-plasm, and the body of a dog from dog germ-plasm. It follows that there must be as many different kinds of germ-plasm as there are species of many-celled animals and plants, and of course we ask ourselves in what these differences consist. This is a question indeed, for we may look through the microscope at the germ-plasm of man, the oak, the ox, the mouse, the lily, and find very little difference between them; a cell is a cell, a nucleus is a nucleus, and there is little more to say. Indeed, many people have argued most improperly, as if the apparent similarity between the germinal material which will develop such different results were real, and as if it were much of a toss-up, so to speak, whether a man or a monkey should develop from the germinal material in any particular case. But nothing whatever could be further from the truth. The similarity between the germinal material of such various species simply proves how far our microscopes are from seeing into the depths.

It is a great pity that the popular writers on this subject, especially those who care for it not on its own account but as an argument in favor of materialism, have not derived from Weismann not only some of his mere knowledge, but also some of the wisdom which caused this great and humble thinker to conclude his masterpiece with the words: "We are thus reminded afresh that we have to deal not only with the infinitely great, but also with the infinitely small; the idea of size is a purely relative one, and on either hand extends infinity."

The humility of Weismann an example to lesser thinkers

Thus clear-seeing Weismann made the only just inference from the microscopic similarity of different germ-plasms, which we have just described. He saw that there must be what he called an "architecture of the germ-plasm", ultra-microscopic in dimensions, but none the less real and characteristic; and that this architecture is special and unique for the germ-plasms of each and every species. The germ-cells that would have become the beginnings of monkeys, mice or men may be substantially indistinguishable by any microscope, but if we could see closely enough into the details of their architecture, we should find them just as characteristic and just as different as are the developed bodies of a monkey, a mouse and a man

Of course, no one's mind can stop there. Once we realize that, in the tiny cell under our microscope, there is such a structure that when two such cells, essentially similar, unite they will produce a horse, or an oak, or a man, we are bound to ask ourselves what the details of its astonishing architecture can be. Perhaps the reader appreciates the attractiveness and the unthinkable difficulty of the problem. At any rate, we have all been arguing about it ever since Weismann's propositions were first laid down, and we shall argue about it for ages to come, beyond a doubt.

The over-elaboration of Weismann's idea of architecture in the cell

It is only quite recently that we have begun to think of the problem in terms of chemistry, as will be seen, but until then it presented itself as one wholly of physical structure, or, to use Weismann's own term,

"architecture". Weismann himself constructed a most elaborate and ingenious description of what, as he supposes, must be the architecture of a germ-cell. Innumerable writers have criticized his views and have put forward views of their own. Weismann went on elaborating his scheme and multiplying his names of structures supposed to exist in the germ-cell, which no one has ever seen, or ever can see, even if they exist; and thus he laid himself open to a great deal of ridicule and destructive criticism. He overloaded his fundamental ideas with so much further and dubious material that the whole structure has long been top-heavy. Here we shall pay very little attention to this part of Weismann's work, which is not in the least degree essential to Weismannism, properly so-called, and which is merely the center of an interminable and futile controversy, where the object of the game seems to be to find out who shall coin the largest number of the longest new words in the shortest possible time.

Waning of idea of architecture in the cell under discovery of chemical action

But our chief reason for avoiding any detailed reference to the views of Weismann and the other microscopists and theorists regarding the architecture of the germ-plasm is that the results of modern Mendelism are hinting at a chemistry of the germ-plasm which shall be something deeper even than its architecture. We are beginning to see how the development of this or that feature in the body of the new individual may depend not upon the existence, in the germ-plasm, of some special tiny structure from which it was formed as the creature grew, but perhaps upon the presence or absence, in that germ plasm, of a particular chemical ferment, the presence of which would initiate a certain series of developments, ending in some particular characteristic of the individual, whereas in the absence of this chemical initiative none of those changes would occur, and the particular final result in question would also be absent. The reader will observe the radical difference between such an idea and the idea that, for each characteristic organ or feature of the body, there must have been a corresponding group of units, having a particular arrangement, or "architecture", in the germ. That older view led to endless difficulties; and Weismann's statement of it, and those of his critics, were always in need of further elaboration and piling up of complexities, in the hopeless attempt to imagine some architecture of the germ-plasm which should somehow comprise, in that little space and in that simple guise, a sort of counterfeit presentment of the adult body in all its myriad parts. Here bio-chemistry, or the chemistry of life, is beginning to come to our aid, and is making most of the top-hamper of Weismannism obsolete. We shall confine ourselves here to its great principles, which, in the light of present-day knowledge, have undoubtedly triumphed.

Weismann's location of the germ-plasm in the nuclear chromatin of the germ-cell

We have said that the germ-plasm has been given a local habitation in the nuclei of the germ-cells from which all the higher animals and plants are developed. We must try to locate it more narrowly still. The centrosome, which initiates nuclear division, is no part of the germ-plasm The germ-plasm is equally present in the nuclei of germ-cells derived from male and female organisms, though only one of these may possess a centrosome. But we have already seen that the nuclear substance of a germ-cell, like that of any cell, consists of two distinct and sharply contrasted parts — one which readily takes the color of certain dyes, being therefore called the chromatin, while the rest of the nucleus does not stain with those dyes, and is therefore called the achromatin. When the nucleus undergoes the changes associated with division, we learn that the chromatin is the all-important substance. It is the chromatin that breaks up into chromosomes, which are split and distributed between the daughter-cells. On these grounds Weismann has located his germ-plasm in the chromatin of the nucleus, or, in his own words, "the chromatin must be the hereditary substance".

We have already seen how far the microscope will take us in the study of the germ-plasm, assuming that the nuclear chromatin in a germ-cell is the germ-plasm The microscope shows that the chromatin breaks up into chromosomes, which split. It also enables us to detect, more or less distinctly, a row of smaller units within each chromosome, in some cases. But there the microscope leaves us. It becomes necessary to have recourse to the microscope of the mind in order to form some idea of what *must* be the ultimate structure of the germ-plasm — which has to account for all the characteristics of the developed body of a tree, a whale or a man.

What imaginative inference says when the microscope fails to carry us farther

Here we shall follow Weismann only in mere outline, and cautiously, remembering how difficult and speculative our inquiry must become from the moment at which the microscope fails us. But Herbert Spencer has already prepared us, in some degree. He argued that the substance of a living body must be made up not merely of cells, nor merely of chemical molecules, themselves lifeless, composing those cells, but also of units, smaller than cells, but larger than molecules, and individually alive, which he called physiological units. Undoubtedly there must be such things; and Weismann, like all students of this subject since Herbert Spencer, recognized the necessity of their existence, and named them afresh. In Weismann's system these smallest units of living substance, called "physiological units" by the first man to recognize that they must exist, are called *biophors*, or "bearers of life".

The infinite complexity of the most minute physiological units

People are sometimes guilty of speaking of a "molecule of protoplasm", but this only means that they can have no idea of the complexity of protoplasm or living matter. The simplest protoplasm must consist of groups of molecules, each group containing many different kinds of chemical molecules. Each such vital or physiological unit is itself alive, and a biophor, or bearer of life. It is the smallest imaginable portion of living substance, and we must suppose it to be capable of nutrition and respiration, excretion, growth and multiplication. We say we must suppose it to be so capable, but we are the sorriest fools if we suppose that we understand how it can be so capable Only in terms of something which is purposive Mind can we now be satisfied.

But next we have to conceive of these ultimate vital units or biophors, each consisting of a group of various chemical molecules, as being themselves grouped so as to form larger units within the germ-plasm or chromatic substance of the nucleus of a germ-cell. These larger units, each composed of various but perfectly definite numbers and combinations of biophors, were called "determinants" by Weismann; and this name has become famous in biology. There is no doubt that something of the nature of Weismann's determinants must exist in the germ-plasm, and

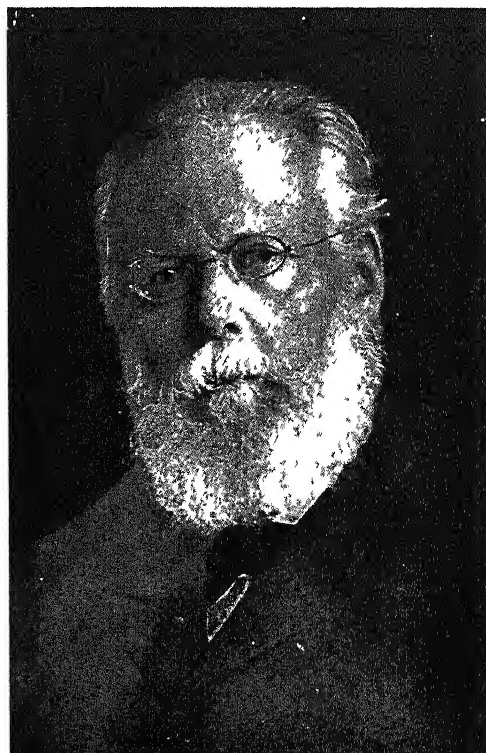


Photo C. Ruf

AUGUST WEISMANN

he gave them this name because each determinant must be regarded as determining the development of the various features of the future body. Thus, for instance, Weismann conceived that there must be a special determinant or group of biophors in the germ-plasm of any of the higher animals which will lead to the development, in its body, of the red blood corpuscles. These are all similar, but different from everything else in the body; and therefore it is argued that they must be represented in the germ-plasm by a determinant, which determines their formation. Further than this point we shall not follow Weismann in this particular direction; but he has a further building up of determinants into "ids" and "idants", and so forth, which have been immensely discussed, but are losing their interest in these Mendelian days. Still more complicated must the speculations become when we try to account for new characteristics or true variations, in terms of what happens among these biophors and determinants and so on; but while these speculations may here be wholly ignored, one fundamental truth of the first importance, which we owe above all to Weismann, must be stated. It is, in his own words, that: "Since all parts of the organism are determined from the germ onwards, permanent variations in these parts can only originate from variations in the germ." In other words, true variation is something that happens in germ-cells, and there alone.

Nowadays we hear much less than formerly of Weismann's "determinants", but we yearly hear more about "factors" in the germ-cells, which are responsible for the characters of the developed individual. These "factors", which the Mendelians are bound to assume in the germ-cells, and the behavior of which they are elucidating, correspond in all essentials to Weismann's idea; but again we must note that, while he thought of his "determinants" in the language of architecture, modern genetics inclines to think of its "factors" more in terms of chemistry — such as the presence or absence of a particular kind of ferment in the germ-cell.

True variation, we said, is something that happens in germ-cells; and this leads us on to the question of the origin of germ-cells. In a few cases a true "continuity of germ cells" from one generation to the next can be observed; for when the "zygote" divides, it begins by setting on one side, so to speak, the germ-cells for the next generation, and then proceeds to form the body which will house them. But as a rule this cannot be observed. Even so, we have evidence to show that, at a very early stage, part of the developing individual is set aside for the formation of the germ-cells, while the rest goes on to form the individual body. That is all we can assert, in terms of the visible, but it is sufficient, if it be understood to justify us in assuming that some special germinal material, the germ-plasm, has been handed on continuously from one generation to the next, and has not been made by the body of the individual.

So much we must grant to Weismann, but unfortunately too many students of biology have rested content with these striking phrases about the continuity and immortality of the germ-plasm, and have forgotten the very certain and long-known fact that the process of formation of the actual germ-cells goes on in the body of the individual, though not exactly *by* the body of the individual, of either sex, throughout the whole of its reproductive period.

The relation between a continuous germ-plasm and individual development

To forget this is to erect the doctrine of Weismann into a worse than useless fetish; and we must beware. Needless to say, Weismann never made such a mistake himself. On the contrary, he it is who described the phenomenon of "reduction", whereby the number of chromosomes is halved when the final "ripe" germ-cell is formed, ready for mating. This ripening or maturation of the germ-cells, as it used to be called, occurs, of course, in the body of the individual, and involves active processes of nutrition which are dependent upon the blood of the individual in whom they occur.

These ripenings and maturations, presenting strange and characteristic features in both sexes, are now fairly well understood; and we shall see that unparalleled importance must really attach to them in relation to the origin of true or germinal variations. The modern name for this process, in either sex, is "gametogenesis", as we have seen, its results being the gametes or marrying cells, which are the final, ripe germ-cells, capable of mating to form the new individual, or zygote.

Necessary precaution against unreserved acceptance of Weismann's theories

Let us, then, by all means accept the essential teaching of Weismann as to the continuous germ-plasm, not made from the body of the individual, but the maker of the body, which then houses it, and passes it on. But let us also realize that this is a half-mystical doctrine, which must not be held in any such form as to deny the known facts of observation. The chief of those known facts is that the germ-plasm takes its active embodiment in germ-cells — obviously, if it is not in them it is nowhere — and that these germ-cells are not simply a collection of finished products, which the body is provided with from the first, and then merely houses, but are cells that are constantly being made, in the body, from preceding cells found in the testis or ovary of the body in question. The vital importance of this fact of gametogenesis is two-fold.

First, we have to conceive of the germ-plasm as intensely alive, active, changeable, dynamic, *not* as a passive and constant thing, immutable and immortal, which is simply handed on from generation to generation unchanged. It must be intensely alive, which means intensely changeable, for, in point of fact, throughout the whole reproductive period of the individual, this germ-plasm, which we have located in the chromatin of the nuclei of the germ-cells, and of the precursors of the germ-cells, is producing those germ-cells, each unique and distinctive. The differences between brothers and sisters of the same parents are ultimately determined by the determinants in the germ-cells whence their bodies were formed; and just as brothers and sisters differ, so must the various germ-cells, produced even from the germ-plasm of one particular person, differ, and equally.

The confirmation of Weismann's theory by the experiments of Mendelism

The formation of ripe germ-cells, or gametogenesis, as we now call it, is therefore the process in and by which the endless variations of living things are created; and plainly we must study gametogenesis with zeal in consequence, for upon its variations all organic evolution depends.

After a period of doubt, due to the misunderstandings of "biometricians", who confounded the mere effects of nurture with true variations, we have come back to the view set forth first by Weismann: that bi-sexual reproduction is a cause of variations. We see that the process of gametogenesis, and reduction of the chromosomes, so that each gamete is in a sense only half a cell, though it appears to be structurally complete, must lead to the production of variations, because of the mixture of two germ-plasms, and the creation of a new and unique germ-plasm in consequence, whenever a new zygote is formed. This theory of Weismann, by which he explains the utility of bi-sexual reproduction at all, is now absolutely confirmed, of course, by the facts of Mendelism, which show the importance of each particular mating of two gametes, and the consequent production of variations, which may sometimes be very startling.

But the recognition of this process of gametogenesis, steadily occurring in the body of the mature individual, is of vital importance for a second reason, as we have said; and this is that we now learn how greatly the "germ-plasm", with all its "immortality", is dependent upon the body which houses it. Thus, if that body is equipped with blood in which lead, alcohol, arsenic, certain disease toxins or other racial poisons, as the eugenists call them, are contained, the process of gametogenesis will be prejudiced accordingly, and the results may be of the gravest. On the other hand, the body of the individual

in which gametogenesis is occurring may be providing the germ-plasm with perfectly healthy and abundant blood, so that gametogenesis will occur favorably. But, unfortunately, these quite obvious truths, fully appreciated by Weismann himself, are apt to be ignored by those who have not read, but who have accepted, the doctrine of the continuity and immortality of the germ-plasm, and of the non-transmission of acquired characters.

The effect of nutrition, good and bad, upon the next generation

They thus assume that the germ-plasm is not merely immortal in Weismann's profound sense, but immortal and inviolable in the sense that nothing which happens to the body can affect the germ-plasm This is palpably foolish, for we know that if and when the body dies, the germ-plasm it contains must die also And similarly, as Galton and Weismann have most carefully stated — apparently to little purpose — the nutrition of the body in general may affect the germ-plasm and the process of gametogenesis for good or for evil, as has now been exhaustively proved, both in animals and plants, in the case of many kinds of disordered or abnormal nutrition.

This is a fact of high importance for eugenics, no doubt, but it is of at least equal importance for the science of life, showing that the variations which arise in the process of germ-cell formation, or gametogenesis, and which are the essential condition of all organic evolution, may themselves be conditioned by the nutrition of the individual body in which these processes are occurring. We thus return to reason and common sense, and the doctrine which Lamarck taught a century ago. If the reader cannot distinguish between the assertion that, say, development of the parental biceps will modify the germ-plasm so that the child will have a bigger biceps than otherwise, and the proposition that, though this does not happen, yet the nutrition of the parental body affects the germ-plasm which it houses — well, there is no help for it.

The variation of germ-plasms in consequence of external influence

He has the consolation of being in distinguished company, but Galton and Weismann themselves are not of the number When Galton denied the so-called "transmission of acquired characters", he carefully excluded the infection of germ-plasm by microbes, and the influence of disordered nutrition. Weismann did the same.

He pointed out that what occurs to the germ-plasm in many cases of parental alcoholism is not, strictly speaking, a problem in pure heredity, but is simply "an affection of the germ by means of an external influence", and we see what he means. But in one respect we must modify his conclusion. He argued that such affections of the germ by an external influence, such as alcohol, quinine or what not, will produce degeneration, but he denied that any such chemical treatment, as we may call it, of the germ-plasm can cause the development of new and positive features. There, however, modern experiment is against him, for the American botanists have definitely produced new forms by just such processes Weismann himself subsequently admitted that in earlier days he "did not attach sufficient importance to the variation of the germ-plasm in consequence of influences acting directly".

Disciples who are more favorable to a master's ideas than the master

With that very important admission, still ignored by the too faithful Weismannians, who are "*plus royalistes que le roi*", we may leave this great pioneer, whose leading ideas are now part of the accepted achievement of biology, and who lived on into the new epoch when his ideas of the nature and origin of germ-cells are being immensely extended, as well as confirmed, by the application of the discovery which Mendel made some years before Weismann began to write at all. With this chapter, then, an era in biology closes; and we proceed to the new-old work of the solitary pioneer of Brünn, which dominates all our inquiries today.

A PLANT'S LIFE-PROCESSES

Buds and Leaves—Their Structure, Development, Action and Uses

HOW A PLANT FEEDS AND BREATHES

UP to this point in our study of the physiology of plant nutrition, we have been chiefly concerned with that source of the food supply of the plant derived from the various constituents in the soil in which the plant is growing. We have noted what these constituents were, how they came to assume such a form that the plant could utilize them, and how the plant itself managed to extract them from the soil, and transfer them into its own tissue cells. The organs of the plant concerned in this part of the process of nutrition were, as we have seen, the various forms of roots and their appendages, these, taken together, constituting the whole root system of the plant in question.

The absorption from the soil of all these various food supplies, by means of the root, provided nourishment not merely for the immediate needs of the developing young plant, but also, by means of the immense and varied arrangement which different plants develop, enabled in most cases a considerable supply of surplus food to be stored up, either in the seedling, for the benefit of the young embryo, or in special forms of underground stems, for the purpose of enabling a plant to live for a winter period, and to start vigorous growth in the spring. Or this food may remain actually in the stem of the plant itself for purposes of general nutrition.

But there is a second function in plant nutrition which is just as important as is that carried out by the root system, and that is the function of breathing, or respiration; and the study of this aspect of plant life brings us to the question of the buds and leaves of plants.

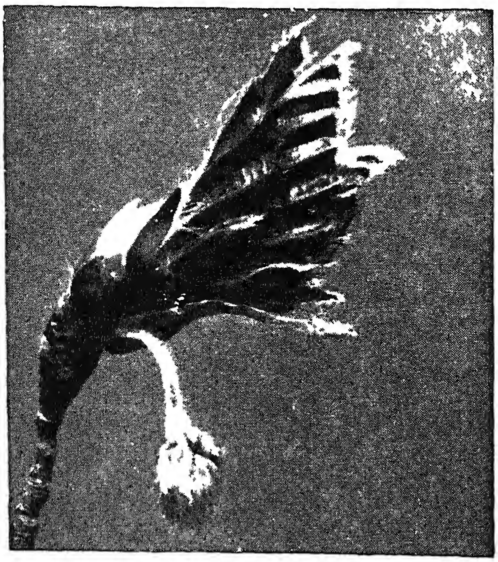
A close examination of a growing young stem will show the presence upon it of a number of bud-scales, having different positions and arrangements with reference to each other in different species. This can be best noticed just before the leaves begin to appear, because the early stage of a leaf is found in the bud. An examination of a series of these bud-scales gives a complete picture of all the stages between the bud-scales and the perfect leaf. These buds may be distinguished as either lateral or terminal, according to their position on the stem. Some are termed "winter buds", these being capable of living throughout the whole of the cold weather on account of their scaly nature, while others are naked buds, having no special protective scaly covering. Such naked buds are those seen on the common geraniums. The original terminal bud of a plant is, of course, the plumule itself. Most of the lateral buds are to be found in the angle formed by the stem and the stalk of a leaf, and such buds are termed "axillary" in position. Buds other than axillary ones are often referred to as "accessory".

As a matter of fact, the term "bud" itself may imply almost any part of a plant which is in an undeveloped stage, the bud merely being a promise of something to come; so that we may regard buds as being either leaf-buds, or flower-buds, or mixed buds, the last being those which contain both leaves and flowers as yet undeveloped.

The most perfect example of the general structure and arrangement of a typical bud is to be found in plants with a large

terminal bud, such, for example, as a small cabbage, especially of the red variety, where the parts are condensed closely together, showing their arrangement one to the other. If the head of such a plant be cut longitudinally, we observe a short, thick stem with a large number of closely packed leaves arising from it (the outer ones being the older), and then a number of axillary buds lying in the angle between these leaves and the stem.

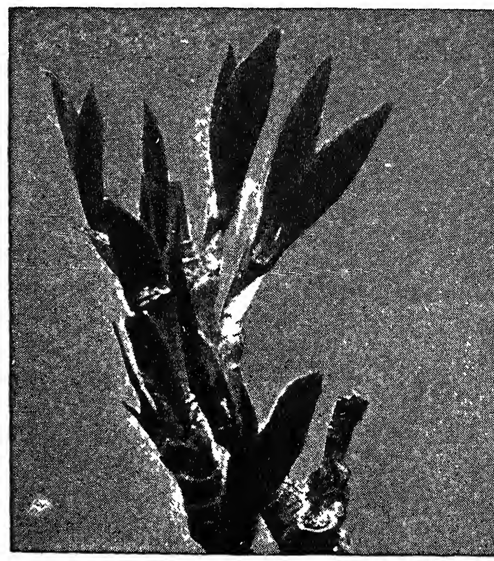
At a later stage in growth the arrangement of the leaves themselves can be better seen, and this arrangement differs in different plants. It is termed the "vernation" of the plant.



FAN-LIKE VERNATION OF BEECH LEAVES

The following examples of differing vernation may be noted: In the cherry, the leaf has its halves folded flatly together, the young surface being external. In the walnut the separate parts of the leaf (the "leaflets", as we may term them) are folded flat into a conical arrangement. In the wood-sorrel the three leaflets of which the leaf is composed are folded smoothly together. In other plants there is a fan-like arrangement. This type of vernation may be best realized by a glance at the illustrations in this chapter.

The object of all the different leaf arrangements or vernations is at least twofold. In the first place, economy of space has to be studied in the young plant, and the leaves are therefore packed as closely together as can be conveniently managed. In the second place, it must be remembered that on their first appearance the young leaves are extremely soft and delicate structures, and are unable literally to stand up for themselves until they attain such a growth as involves firmness in their texture. They must therefore be protected both from heat and dryness until they are able to assume the vertical attitude on their own behalf, otherwise they would wither under the heat of the sun at midday. Protection also must be afforded as far as possible from the attacks



ADVENTITIOUS BUDS ON CLIPPED LAUREL

of insect and parasitic growths; and this is frequently furnished either by a superficial covering of a soft, downy nature, or by a special scaly covering.

The buds which occur neither at the terminal portion of the stem, nor in the axils of the leaves, are termed "adventitious". Good examples of such buds are seen when plants are injured, either intentionally or accidentally, as, for example, when they are cut back, a proceeding which causes buds to develop in positions where otherwise there would be none. In other cases the terminal bud does not appear at all, as in the lilac, and the result of this is seen in the complicated branch of the plant.

So that, to summarize, we find that buds are composed of coverings and the contents within, the latter being either leaf-buds, flower-buds or mixed buds; and the position of any of these may be normal or abnormal.

Now let us turn our attention to the study of the leaf itself, a structure to which botanists have devoted great attention, partly because the leaf offers a basis for classification and identification. The result is that a great number of technical botanical terms are in use to describe the general and minute structure of leaves. As regards their outlines in general there is immense variation; thus, the whole leaf may be heart-shaped, arrow-shaped, almost round, elongated, much divided and so forth. Similar variation is seen in the nature of its margin, which may be finely serrate, coarsely serrate, doubly serrate, dentate, wavy, crenate, etc.

Then the veins in the leaves, which are very important structures, also exhibit considerable variation in their arrangement, but in every case adapted so as to give the chief support to such portions of the leaf as need it most; and it may be also noted that the arrangement of the leaves, with reference to the stem, has some general relationship to the shape of the leaf and the arrangement of the veins. Thus, the elongated leaves frequently show the veins running through them in a more or less parallel direction — either running from one end of the leaf to the other, or coming off from the midrib and running in parallel lines to the margin of the leaf. Such plants as the lilies, the grasses and the sedges all exhibit leaves with parallel veins. In other cases the arrangement of the veins in a leaf suggests a distinct network; and it is a curious fact that this network arrangement is found in plants which have two cotyledons.

When the leaf seems to consist of one single piece, it is referred to as a "simple" leaf; when, on the other hand, it is doubly cut in two, as in the dandelion, it is spoken of as "runcinate", or "divided". But sometimes the leaf is not a simple one at all, but what is described as "compound", when the midrib appears to carry what, at first sight, look like a number of separate leaves, but in reality are divisions of one. The horse-chestnut is an example of a plant bearing a compound leaf, the portions of which do not all wither at the same time. Whether such a leaf is to be regarded as a simple or a compound one may be tested by the presence or absence of buds in the axil, among other things.

HAIRY BUD OF BEGONIA

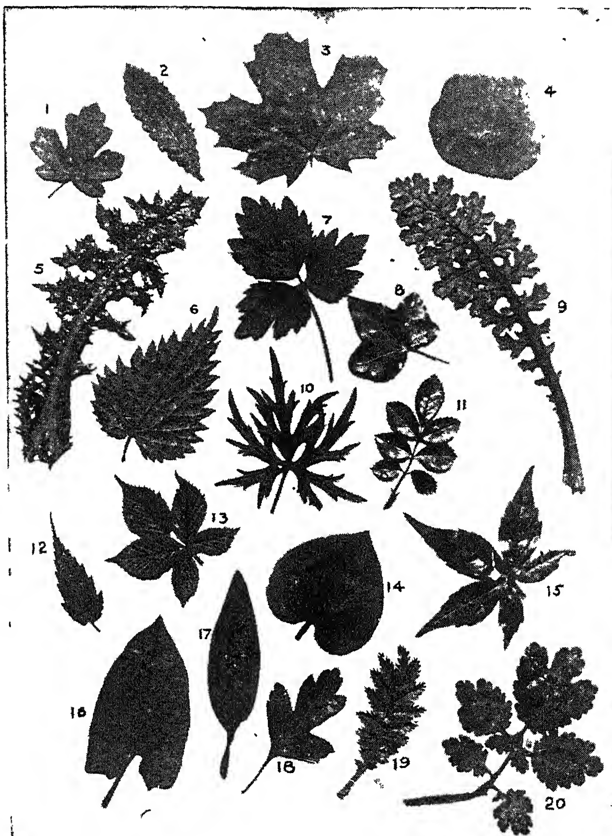
SCALY BEECH-BUD

DOWNY BUD OF LUPIN

It will be necessary at this stage, before taking up the detailed consideration of the physiology of roots, stems and leaves, to say a few words in connection

with their anatomical structure, with especial reference to the diagrams and illustrations in this section of our work. If we examine the stem of a dicotyledon we find that most of it is made up of somewhat soft tissue, with some tougher strands running through it. These latter constitute those very important elements in plants known as "vascular bundles".

These have two functions — first, that of a circulation which distributes the sap to the different parts of the plant; secondly, they act partly as a skeleton, giving firmness and support. On the outside of the skin of the stem is a layer of cells, called here, as in animals, the "epidermis". All the rest of the tissue, in such a simple stem, consists of what is termed "ground tissue". The vascular bundles are seen to be arranged in a circle; and that part of the stem which is inclosed in this circle is the medulla, or pith, while the part outside the vascular bundle of the circle is the cortex. The narrow portions of tissue running between the bundles connecting the pith with the cortex are the medullary rays.



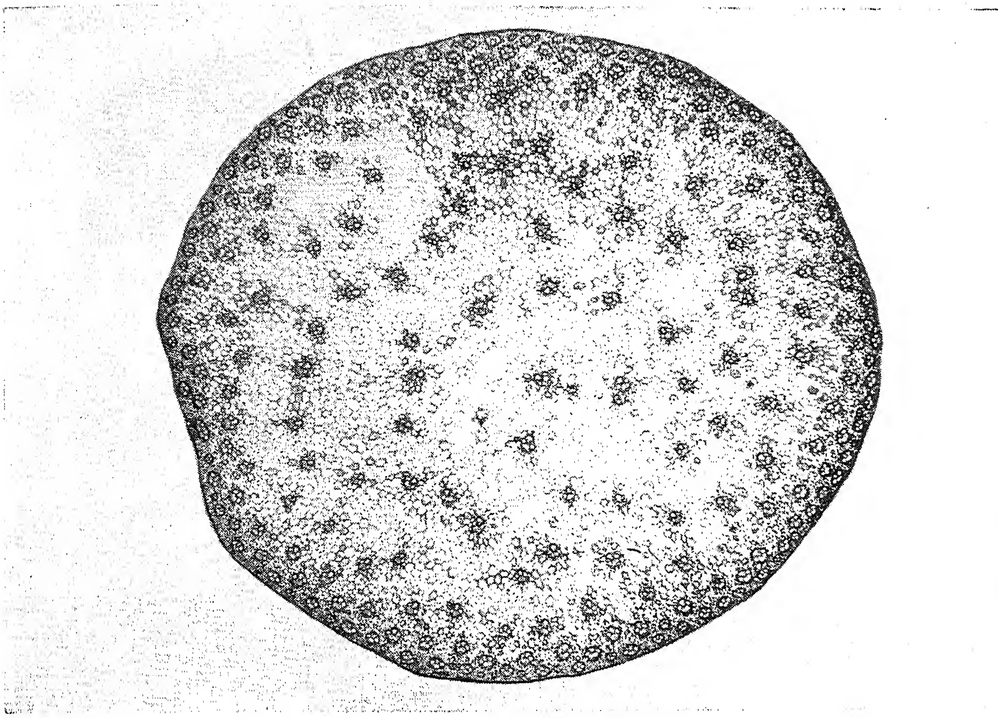
SIMPLE, DIVIDED AND COMPOUND LEAVES, SHOWING VARIATION OF LEAF MARGINS

1, maple; 2, thistle; 3, plane-tree; 4, nasturtium; 5, sow-thistle; 6, stinging nettle; 7, buttercup; 8, ivy; 9, ragwort; 10, buttercup; 11, rose; 12, kerria; 13, blackberry; 14, aristolochia; 15, Virginia creeper; 16, bindweed; 17, alstromeria; 18, hawthorn; 19, silver weed; 20, greater celandine.

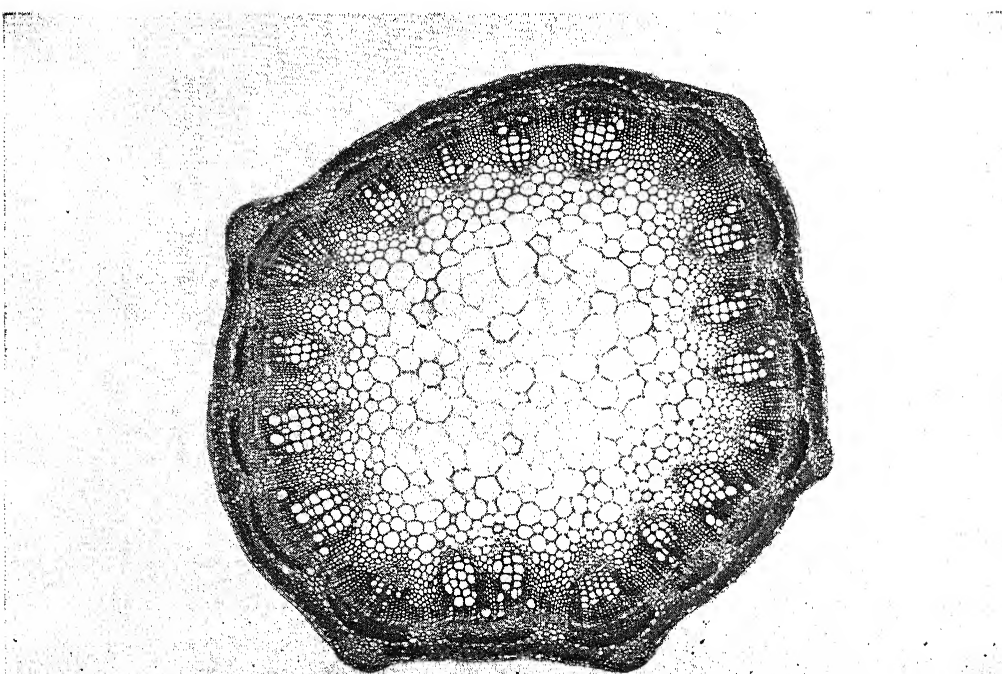
The epidermis of such a plant is usually found to consist of a single layer of cells. Its function is protective from weather and injuries, and also it hinders the too rapid loss of moisture. Here and there among the cells of the epidermis, openings are found, that are called "stomata". On many leaves, and on some stems, the peculiar and beautiful appearance known as the "bloom" may be seen: and this is in reality a waxy secretion produced by the cells of the epidermis. Where it exists the loss from water is less than it is at other parts, and it possibly also assists in warding off insects and molds. The epidermic cells do not usually contain the green coloring matter found in leaves, but instead frequently contain coloring matters of a reddish or purple color. In addition the epidermis frequently is covered with hairs which are really modified cells and serve to protect the stem from the attacks of insects and bacteria. Other hairs act as glands and produce oily or sticky substances, which are also protective.

A transverse section of a vascular bundle taken from the stem of a herbaceous plant shows that it is composed of (1) wood, or xylem; (2) bast, or phloëm; and (3) cambium. The details of these parts are shown in some of the illustrations in this chapter.

If we compare with the above the stem of a monocotyledon we find a somewhat different arrangement of the vascular bundles. They are no longer found in a



This diagram shows the scattered vascular bundles in the stem of a monocotyledon — a corn plant.

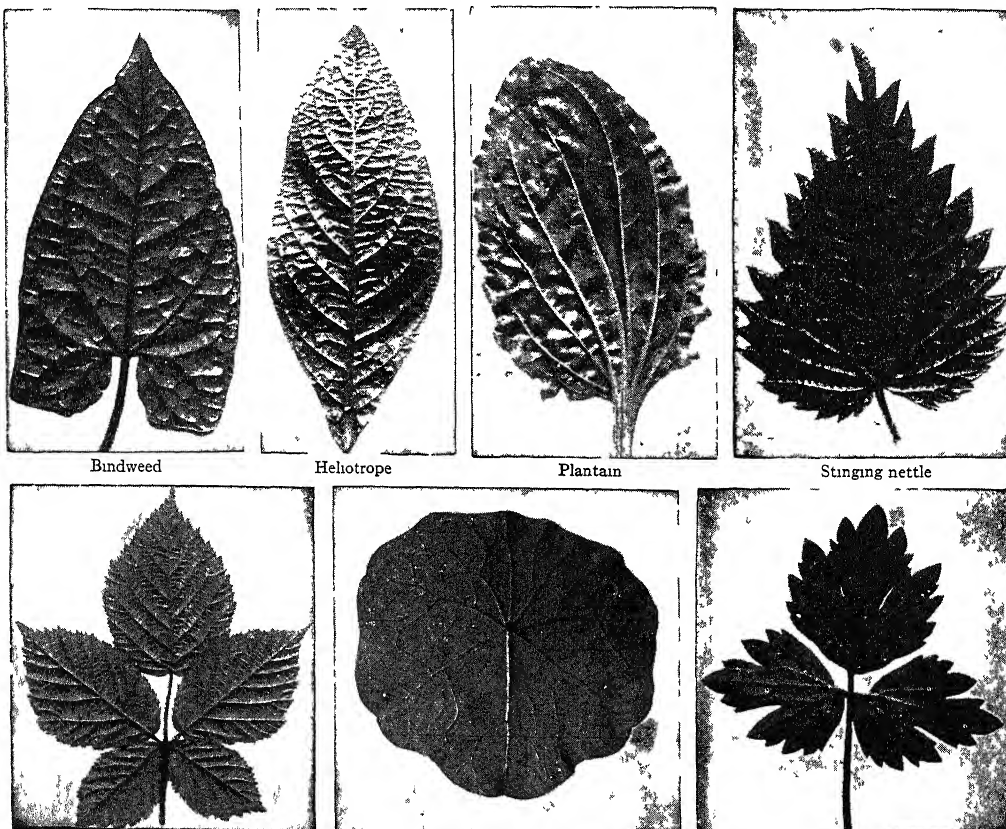


Triarch Botanical Products

Above we see the encircling vascular bundles in the stem of a typical dicotyledon — an alfalfa plant.

single ring, but are scattered through the ground tissue The result is that the pith, or medulla, is not seen so distinctly, and the cortex is very narrow. In both these, and in the dicotyledons, the vascular bundles are continuous from the stem to the leaf.

Next, as to the minute structure of the leaf itself It is made up of precisely the same elements as are both stems and roots; that is to say, it consists of a ground tissue in which run the vascular bundles, the whole being covered externally by epidermis. The vascular bundles in a leaf of a dicotyledon branch so as to form a network, which is both a means of sap circulation and also a supporting framework. In a monocotyledon, on the other hand, the vascular bundles as a rule run parallel, and in the body of the leaf. The epidermis, here as in the stem, consists of a single layer of cells whose outer walls are protective, and which are continuous with the epidermis of the stem. Here, too, are stomata, as in the stem, each stoma consisting of two curiously shaped cells, termed "guard-cells", placed in contact with each other so as to leave an aperture into an air-chamber within. These stomata are organs of very great importance, since they allow of the moisture escaping from the leaf in transpiration, and in addition play an important part in the exchange of gases between the plant and the atmosphere — that is to say, in the function of respiration.



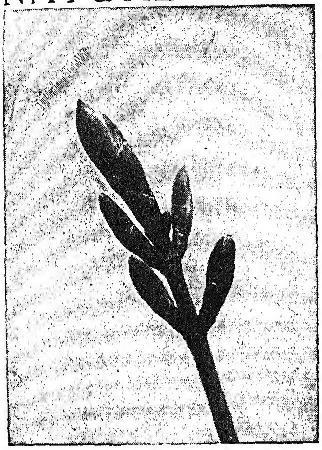
Bindweed Heliotrope Plantain Stinging nettle

Blackberry Nasturtium Buttercup

EXAMPLES OF VENATION IN VARIOUS TYPES OF LEAVES

The ground tissue in the leaf, which is continuous with that of the cortex, is usually divided into two parts — that immediately under the epidermis of the upper aspect of the leaf, and the other portion which lies between the lower layers of epidermis. In this ground tissue in the leaf is found the green coloring

NATURE AS MAKER OF MOSAIC PATTERNS



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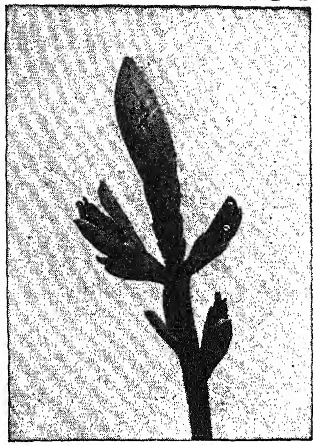


MAY 1

MAY 2

MAY 3

MAY 4

MAY 5

MAY 6

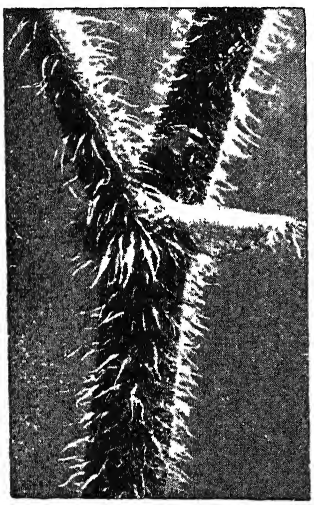
MAY 15

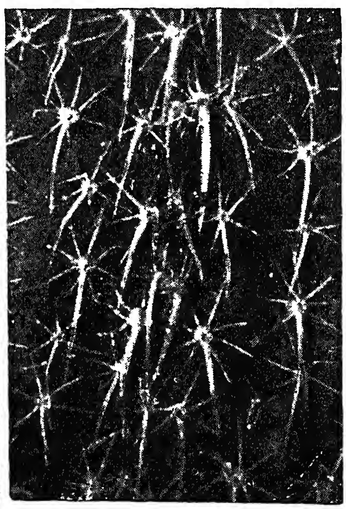
IN FULL LEAF

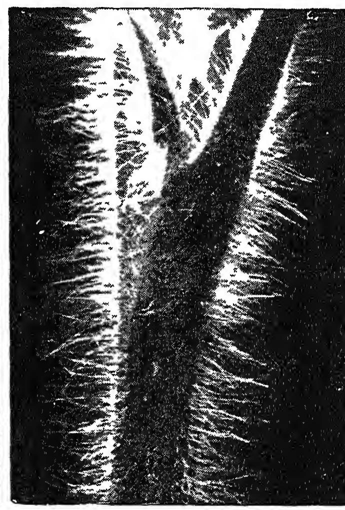
THE DEVELOPMENT OF THE WINTER BUD OF THE SYCAMORE INTO ITS LEAF-PATTERN

matter, or chlorophyll. An examination of the upper surface of most green leaves will show that the green color is rather deeper on that side than on the under surface. This is because the chlorophyll is more dense in the upper cells, which themselves are packed closely together.

Now we are in a position to turn our attention in greater detail to the actual performance of the functions which these structures carry out on behalf of the plant. All land plants that are alive are continuously giving off from themselves a certain amount of water in a vaporous condition. This process is called "transpiration", and is something quite different from the giving off of water from a wet cloth hung out to dry The latter is a mere question of evaporation. The transpiration of a plant, however, is a living physiological function, controlled by the cell protoplasm. The actual quantity of moisture thus given off by transpiration has been measured for some plants, and stated to be twenty ounces in twelve hours for a sunflower three and a half feet high. A cabbage in the same time transpired fifteen ounces. These rather large quantities show that a crop of cabbages would drain from an acre of land several tons of water per day; and as this must come from the water in the soil it is obvious that such soil, having upon it a heavy crop, will tend to dry up quickly.


HAIRY STEM OF BEGONIA


HAIRS ON A LEAF OF BORAGE


HAIRY STEM OF LUPIN

The process of transpiration varies with the kind of cells on the outside of the leaf, the covering of hairs if present, and to a certain extent with the external atmospherical conditions. Plants with thick outer cells transpire but slightly. A covering of hairs prevents too rapid transpiration, and the bloom of such fruits as plums has a similar effect. Large leaves necessarily involve much transpiration, and hence the need of a good deal of water So we find plants with thin, small leaves usually in dry places; those with big leaves in damp ones. It is quite obvious that unless the plant is to dry up and wither away, or undergo the process sometimes called "wilting", there must be a sufficient supply of water to its tissues in the form of sap to compensate for that lost in the process of transpiration. Indeed, it is surprising what large quantities of water do pass through plants in this manner — large, that is to say, in proportion to the total size and weight of the plant itself. It has been estimated that a plant of corn will give off about 31 pounds of water in 173 days. A sunflower has been observed to transpire rather more than a pound a day of water for 140 days A grass plant will give off its own weight of water in hot summer weather. If this be estimated for a whole field under grass, it would give no less than about $6\frac{1}{2}$ tons of water, for 24 hours, per acre.

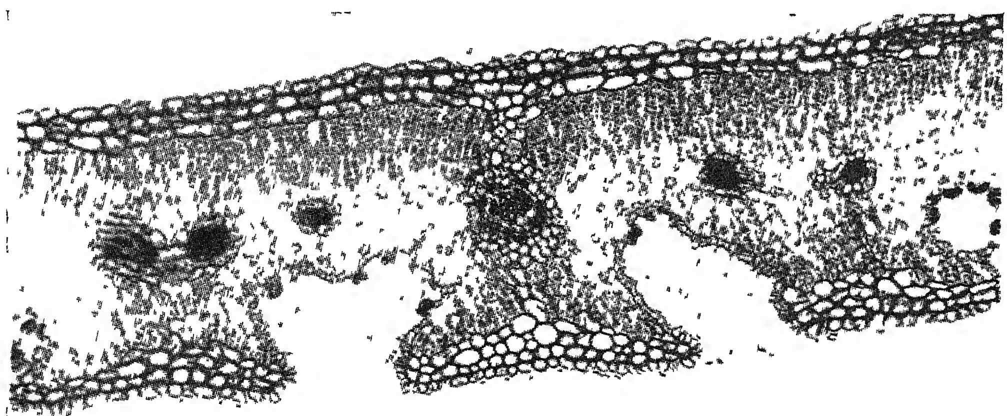
It has been calculated by Joseph Young Bergen that a birch tree, having some 200,000 leaves, and standing in open ground, would transpire on a hot day from 700 to 900 pounds. The figures give some idea of the relatively large quantities of water which must be taken in from the soil in order to supply this loss.

Water is, of course, also the means whereby the mineral matter in the plant reaches it; and this mineral matter is found in old leaves, and is responsible for the large quantity of ash left from a bonfire made of such material.

The next important function performed for the plant by means of its leaves is that of respiration, which must not be confused with the process of transpiration just described. Respiration is practically the same process in both plants and animals, and consists essentially in breathing in oxygen and giving out carbonic acid gas. It is a necessary process in order to obtain energy; and a plant requires energy just as much as does an animal in order that it may grow and reproduce itself. In both plants and animals the great source of energy is oxidation, especially of such substances as fats, starch and sugar. The truth that this process of respiration is just as essential for the life and health of plants as it is for animals can be shown by simply depriving a plant artificially of fresh air. Under such circumstances it very quickly shows signs of failing health. In ordinary outdoor plants there is, of course, no difficulty about this supply of oxygen, but it is very difficult in the case of the roots, which in certain soils cannot obtain as much as they require.

The oxygen required for every single cell enters the plant by means of the stomata in the leaves, and also by apertures in the bark, and it finds its way through the tissues by means of the minute spaces between the cells. The carbon dioxide gas given off is, of course, derived from the substances which make the body of the plant itself, and it is therefore a destructive process as far as plant tissue is concerned. Carbon is lost in respiration just as it is fixed in the opposite process of assimilation. The respiration process is a continuous one in all cells, going on both day and night, whereas the process of fixing carbon in the tissues of the plant is restricted to special cells—namely, those which contain the green coloring matter, and is, moreover, only performed by these in the presence of sunlight.

These two processes of respiration and carbon fixation are going on simultaneously during daylight, but much more carbon is used by the plant than is lost by respiration. The result is that the carbon dioxide in the air is continually decreasing, while the oxygen is increasing. Indeed, it is only at night, when the carbon fixation ceases on account of the darkness, that the respiration becomes obvious.



General Biological Supply House, Inc.

Cross section of an oleander leaf. Above is seen the upper epidermis; at the bottom, the lower epidermis. Note the spongy cells and air spaces into which the stomata of the lower epidermis open.

The beginning and end of a long chain of complicated chemical changes

The two recognizable incidents — namely, the absorption of oxygen by the plant, and the giving off of the carbon dioxide gas — are to be looked upon merely as the beginning and the end of a long chain of complicated chemical changes — changes in which the oxidation of starch and sugars and fats takes place, but which are so complicated that many of the intermediate stages are entirely beyond recognition.

This oxidation is what sets free the energy that enables the plant to perform its various functions, just as happens in animals also; and should anything interfere with it, the result is very soon seen in the cessation of the streaming movements of the protoplasm in the cells, as well as in the stoppage of all growth and movements associated with leaves and other organs. We see, therefore, that the absorption of carbon dioxide and the removal of its carbon is a very important function in leaves; and when we remember that this gas is normally present in the atmosphere in the proportion of four parts in every ten thousand, where it is produced by the decay of animals and vegetables, by respiration, and by combustion of all sorts, it is at once clear how important a part is played by plant respiration in nature's scheme of things.

How the leaf can manufacture starch when the chemist is unable to do so

The next important function of the leaf which we may note is the manufacture of starch, composed of hydrogen, carbon and oxygen. Water is, of course, largely composed of hydrogen, so that in these two substances, water and carbonic acid gas, we have the three elements necessary for the chemical processes that result in the formation of starch.

True, it is impossible to produce starch in the chemical laboratory by putting these three elements together, but it is just precisely that performance of which the plant is normally and eminently capable.

The process of manufacture of starch in the plant like what goes on in a mill

The manufacture of starch is one of the active processes constantly going on in the green portions of the plant under suitable conditions of temperature and sunlight, provided only that water and carbonic acid gas are supplied The active agent in the making of starch is the protoplasm of the cell, which may be regarded as the manufacturer, while the chlorophyll bodies are the actual seats of the manufacturing activity.

Indeed, the whole starch-making process has been very aptly compared by various botanical writers to that which goes on in a mill. Thus, the mill itself is represented by the palisade cells, and those underneath them; the raw material used for the manufacture is the carbon dioxide and water. The machinery in the mill is the chlorophyll; the source of the energy by which the mill is driven is the sunlight; the manufactured product turned out by the mill is the starch; and as in most manufactures there are some by-products, so in this case there is one also, which is none other than the oxygen. This simple analogy enables us to clearly grasp this important process. It follows, from what has been said, that plants which do not contain chlorophyll cannot manufacture starch.

Complex nitrogenous compounds produced by assimilation, a function of the leaf

The starch having been made, the process is continued further, and from it sugar is formed, and this in its turn combines with other elements, such as nitrogen and sulphur and phosphorus derived from the soil, so that finally we have produced very complex nitrogenous compounds, from which protoplasm itself is derived as required, and from which also the proteid foods are obtained. This further process of the changing of starch into other compounds is that of assimilation, and is also a function of the leaf. It is, however, not confined to those structures, but is, of course, going on in different parts of the plant.

The brilliant autumnal tints

We see, therefore, that, briefly stated, there are four distinct functions performed by leaves — excretion of water, respiration, starch-making and assimilation.

One further point must be noted before we leave this part of our subject. Every autumn our eyes are delighted by the brilliant tints of autumnal foliage which precede the annual falling of the leaf. The colors are principally those of yellow, shades of red and purple, variously combined, and these colors are caused by the changing and breaking up of the original green chlorophyll. Certain substances are withdrawn from the chlorophyll, and leave it yellow; and, prior to the time when the leaf actually falls, most of the protoplasm of the leaf has been transferred to the branches or the roots, where it can be utilized in the following spring.

The movements made by plants to adapt themselves to sunlight, air and water

Lastly, in connection with leaves, we must note the wonderful and interesting manner in which they adapt themselves to obtain sunlight, air and water, and the curious movements they make in order to attain these ends. Many leaves have daily movements — that is to say, they change their position, or the position of their parts, according to the light and the temperature. If the sun be too hot, some plants can turn the edge of the leaf towards the sun, keeping their surfaces horizontal only when the temperature is cooler. Then there are the movements taking place in the leaf during the night — the so-called "sleep of plants".

The flower that follows the sun hour by hour and so gets its name

The bean and the clover plants are examples of some whose leaves occupy quite different positions at night from those seen in the daytime. In red clover the leaves droop during the night. Many plants in tropical countries fold their leaves together in the hours of darkness, and possibly these sleep-movements have some connection with protection from cold. The movements themselves are produced by structures at the base of the leaf-stalk, which cause the stalk to bend in one direction or another, and so alter the attitude of the leaf. Many leaves — for example, those of the iris — are so arranged as to catch the morning or evening sun fully, whereas the midday sun falls upon their edge. The leaves of many plants show movements which turn them so as to face the light as the direction of the latter changes. The object is evidently to allow the rays to fall upon the surface of the leaf. Hence we usually find leaves so arranged that their upper surface catches most of the light. In some this turning towards the light is so strongly marked as to be continuous during the day, as is the case in the sunflower, which takes its name from this fact.

THE HAIRY GROWTH ON THE LEAF OF SILVER WEED

THE CURIOUS KANGAROOS OF AUSTRALIA

BENNETT'S WALLABY AND ITS YOUNG

THE CERVINE KANGAROO

THE BLACK-TAILED WALLABY IN ITS NATIVE HAUNTS

GREAT GREY KANGAROOS

THE RED KANGAROO

The photographs on these pages are by Lewis Medland, W. P. Dando, C. Grant Lane and others.

THE POUCHED MAMMALS

A Low Type of Small-Brained Animal Approaching the Reptile, and Developed Chiefly in Australia

THE FATE OF THE MONSTERS OF THE PAST

THERE may lurk a mystery in a shoe of patent leather. Beneath the veneer of varnish there may be leather fashioned from the skin of a kangaroo, the hair from which may have gone to the making of a felt hat. Of all existing quadrupeds there is only one order lower than that to which the kangaroo belongs. That is the monotreme order, the order embracing the two egg-laying, warm-blooded mammals which suckle their young. Below that line come the birds and reptiles. The advance of the kangaroo in the scale of life is related to the fine coat that man converts into leather. Not the first kangaroo, but an ancestor, began its upward course, it is believed, by the reciprocal action between brain and hide. Between the interstices of the ancient mail there arose sensitive, unarmored patches of skin by which the brain could more readily receive communications than from the impervious armor covering the rest of the body. The brain developed under stimulation; the area of sensitive skin became more extended. The skin, instead of a horny covering, became a sort of instrument of touch, recording in the brain every contact with a foreign body. There resulted a swifter and more accurate placing of the limbs to meet swift-changing environment; and as the limbs became more readily controlled they developed amplitude, lifting the beast above the physical level, as the growing brain did above the mental plane of the reptile. So, beneath the varnish of the patent leather shoe may lurk the perfected record of one of the elements in the rise of the mammal above the cold-blooded egg-layer

In order to avoid the use of technical terms in our heading, we have the words "pouched mammals" It must not be left at that We have here to deal with the marsupials. Now, as we all know, the term "marsupial" is derived from the Latin *marsupium*, meaning a pouch A man handling a certain species of bat, *Chiromeles torquata*, may exclaim "Here, then, is a marsupial!" For this bat has a pouch in which it carries its newly born offspring. But that is not a marsupial Another man, finding the majority of opossums lacking the external pouch, will receive with incredulity the suggestion that opossums are marsupials. The fact is, the term "marsupial" is not in itself indicative of all the characteristics upon which the naturalist relies for the classification of the order. Apart from certain important peculiarities as to teeth and skull, and the contemptible character of the brain, there is a feature of the marsupial even more striking than the pouch from which the whole order derives its name, and that is the remarkable immaturity of the young at birth The young of the largest kangaroo, an animal exceeding a man in height and bulk, is at birth a tiny, almost shapeless mass of flesh, only about an inch in length, hairless, and covered with so thin a skin that the blood vessels are clearly seen. The future king of leapers is so fragile and delicate that it can scarcely be handled without injury, so helpless that it cannot even suck, but, placed within the marsupial pouch and attached by its mouth to the teat of its dam, is fed by the injection of milk down its throat by means of muscles controlled by the parent.

The mere act of swallowing in the young has to be safeguarded by a special provision, the throat of this extruded embryo being, at this stage of existence, fashioned after the plan of the crocodilian or cetacean throat, in which swallow and air passage are kept apart to prevent choking. Here, then, are evidences as to the order to which the animal belongs. But correlated with these is a prenatal condition of an exceptional character.

All marsupials are non-placental; there is no connection between the developing embryo and the parent body, such as is found in the case of all the higher

THE VULPINE PHALANGER OR OPOSSUM

mammals. As the egg of a bird contains all the nourishment the chick will need until it bursts its shell and may be fed by its parents, so the fertile ovum of the marsupial requires only the warmth of the parent body. The period of prenatal development extends to only thirty-eight or forty days, and then the embryo animal is born, more helpless than the most feeble of birds. The latter have at least the power to raise their heads and open their beaks to be fed, but that is a condition far in advance of the powers of the almost motionless little fragment of life which the marsupial mother pops into her pouch to nurse and nourish until form and strength and knowledge render the young kangaroo, or whatever it be, able to emerge competent and confident. One of the monotremes, the duckbill, broods her eggs in a nest built at the end of a subterranean tunnel; the other, the echidna, or spiny ant-eater, places the eggs in her marsupial pouch and hatches them there. The kangaroo or its congener may be said merely to hatch the ovum within its body and produce the immediate result, more immature than the newly hatched bird, to rear it in a nest forming part and parcel of the parent animal itself.

Authorities differ as to whether the marsupial is excessively primitive or merely degenerate. Formerly it was held to be the fact that the marsupalian was the ancestral type of mammals; it was a widespread order and, in Mesozoic or secondary times, had nearly a world-wide range. Today the only marsupials existing in a state of freedom are restricted, the true opossums and the selvas to the American continent, the others to the Australian region. It seemed to some naturalists, then, judging by the data available, that all mammals had been developed from this or from an ancestral stock. But later investigations have revealed suggestions, in the bandicoot, of a functional placental connection between the embryo and the parent. Is this a vestige or a rudiment? Is it a relic or a beginning? Are we to regard the circumstance as evidence that the non-placentals of today are the degenerate descendants of placental animals, or are we to think that the bandicoots are only at the outset of a placental development? Are we witnessing the end of a cycle or the beginning of one? None among us is qualified to return a positive answer. The clue to the puzzle lies still hidden in the rocks.

The fact as to which we are certain is that the marsupials, shut up for ages incalculable in terms of years, have attained their greatest development in Australasia. By what route they reached their vast asylum, by what land bridge they traveled thither from another continent, there is not yet clear knowledge.

But we do know that at an early stage in mammalian development the great island-continent of Australia received a group of mammals which has no living counterpart in the world today, and that, sheltered from competition with the rest of the animal world, they waxed mighty in bulk and numerous in species. With the exception of certain rodents and bats they form the entire indigenous fauna of Australia. To that must be added a reservation. There is the mysterious dingo dog which, as we have seen in a previous chapter, has been found in fossil form but in proximity to other remains that do not exclude the possibility of its having been long ago introduced into the island-continent by man's agency.

In certain of the islands adjoining Australia placental animals are found with marsupials. We must not jump to the conclusion, however, that the two types have developed side by side. The placentals are the descendants of other placentals that reached these islands long after the way into Australia proper had sunk beneath the sea. With a world to themselves, the marsupials in Australia branched out in many directions. While the majority remained herbivorous, carnivorous animals developed among them. The hideous thylacine, or pouched wolf, now surviving only in Tasmania, had its kin on the Australian mainland, where it attained huge size and power, though it may not have been entirely carnivorous. The Tasmanian devil, too, was represented there. There were bigger kangaroos than any now to be found; while the diprotodon, a gigantic predecessor of the modern marsupial, attained the dimensions of a rhinoceros. Today no native carnivorous animal survives on the Australian mainland bigger than a small cat.

This disappearance of the giants of the Australian fauna is a puzzling problem, ranking with that presented by the complete annihilation of the gigantic animals with which South America once teemed. Why should the mighty animals of insulated Australia have perished? So long as the herbivorous animals remained, there was abundant food for the carnivores; and the food that sufficed to maintain vast hordes of other marsupials must have sufficed for the diprotodon and its allies. There is a gleam of light in a theory enunciated by Professor A. Dendy at the British Association in 1911. Recalling that many groups of animals in the course of their

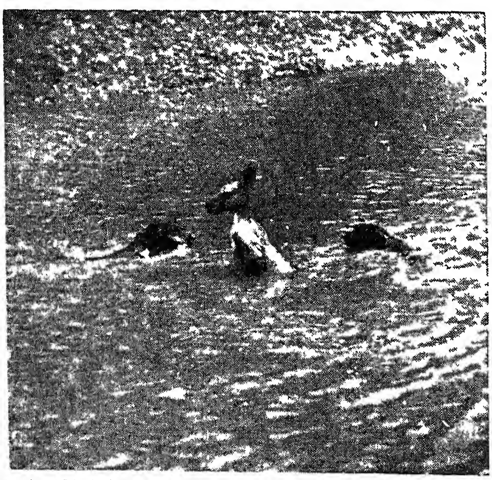
THE KANGAROO POUCHED RAT

evolution have shown a marked tendency to enormous increase in size, and that that tendency has been accompanied by the development of grotesque and apparently useless excrescences, he urges that a race of animals may acquire a momentum of a kind that might lead it to destruction.

THE URSINE TREE-KANGAROO

Normally, there would be a brake applied, as it were, to the growth of organs and organisms and, if that brake were removed, the results might ultimately be fatal. It is generally acknowledged by physiologists that the growth of different parts of the animal body is controlled by internal

secretions, the products of various glands; and there is reason to believe, Professor Dendy holds, that in the absence of certain specific secretions the growth of the various organs would continue far beyond the normal limits. There is no reason, he thinks, why the principle should not be extended to the race · and it might be possible to explain the growth of the organism as a whole, and of its various organs beyond the limits of utility, as an indirect result of natural selection. When a useful organ begins to develop and take on some new function for which an increase of size would be advantageous, natural selection would favor those individuals in which it grew most rapidly and attained the largest size in the individual lifetime



A KANGAROO IN A RIVER KEEPING DOGS AT BAY

If growth were normally inhibited by some specific secretion, natural selection would favor those individuals in which the glands producing the secretion were least developed or least efficient, and this process being repeated from generation to generation, those glands might ultimately be eliminated or might cease to produce the particular secretion. Is it not, therefore, possible, he urges, the normal checks to growth being thus removed along certain lines by the action of natural selection, that a definite direction might be given to the course of evolution which the organism would continue to follow to the bitter end, irrespective of natural selection?

The theory is highly suggestive and, if tenable, throws light on one of the greatest mysteries in the story of animate creation. For though we have the whale, the sea-elephant, the hippopotamus, the rhinoceros, the crust of earth in the Old World and the New is a charnel-house of bones that once were giants exceeding in size any living thing of our day, the biggest whales alone excepted. And in this theory may lie the clue to the disappearance of Australia's mighty beasts where, apparently, every condition was favorable to their possessing the land down to the time of the coming of man.

We must leave it at that, and turn now to a consideration of types still in existence. The order has branched out into so many lines of life as to suggest that nature wished to experiment with marsupials just as with the higher mammals. In the great kangaroos we have purely herbivorous animals which take the place of the ruminants; in the smaller animals we have savage carnivores in the thylacine and Tasmanian devil. We have tree-climbing animals with prehensile tails, denizens of the rocks, burrowers, and adepts at that form of parachuting which we are compelled to term "flying". Further, we have marsupials dependent upon insects for their food; and there is one, the yapock, or water-opossum, which has taken to a semi-aquatic life and is as much at home in river or lake as an otter. We have wolf-like animals, cat-like animals, rat-like, mole-like, bear-like, rabbit-like, mice-like animals; animals out-topping a man; animals tiny as a field-mouse. And all are marsupials.

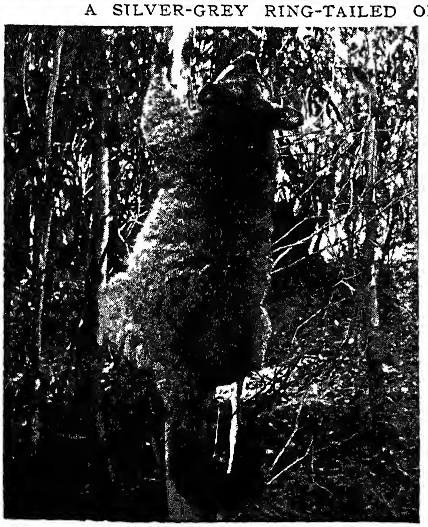
At the head of the list come the kangaroos and their allies, highly specialized in regard to their characteristic leaping progression. This is effected by the remarkable development of the hind limbs, though this feature is less pronounced in the tree-kangaroos. For the rest, the hind legs are of extraordinary length and stoutness, enabling the animal when in flight to progress, not on all-fours, but by prodigious leaps of twenty and thirty feet at a bound. Added to great muscular development in these limbs, it is to be

ARBOREAL MARSUPIALS AT HOME

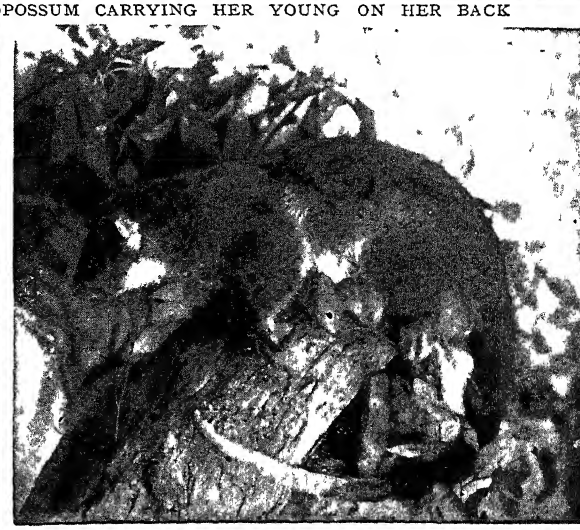
A SUGAR-SQUIRREL PARACHUTING

AN AUSTRALIAN OPOSSUM—RIVER VARIETY

A SILVER-GREY RING-TAILED OPOSSUM CARRYING HER YOUNG ON HER BACK

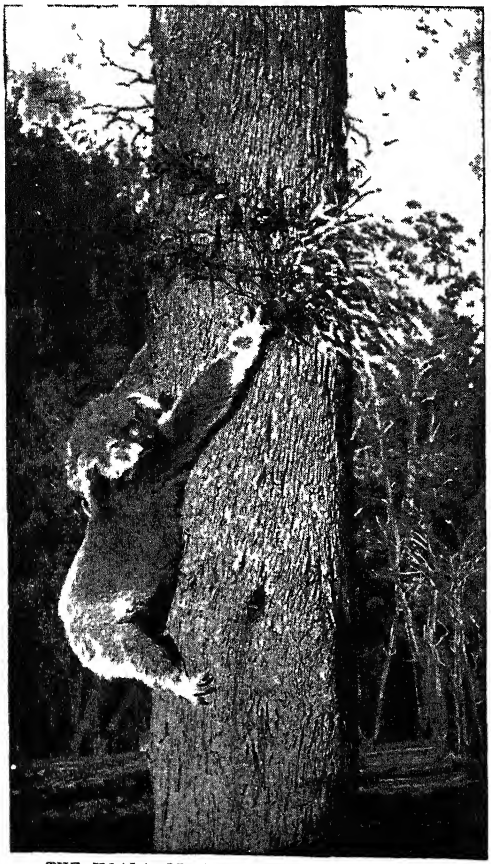


AUSTRALIAN OPOSSUM—HILL VARIETY



A BROWN VARIETY OF RING-TAILED OPOSSUM

noted that the bones here are of an ivory-like density, to withstand the heavy strain and shock to which these sole organs of progress are submitted. For, be it remembered, the fore legs, like the prodigious tail, are never used as a means to locomotion, unless the animals be moving slowly when feeding. The fore limbs are weakly developed and are used as hands. When engaged in combat in the mating season, the males spar with their



THE KOALA OR AUSTRALIAN NATIVE BEAR

hands preparatory to making an opening for a leap upon the enemy, when they bite fiercely with their teeth and strike with their powerfully clawed hind legs.

When hunted by dogs, the kangaroo takes to water if such be available, for with all the stupidity of his brain he has learned that by using his fore paws as hands he can clutch the dog and thrust it under water and keep it there until it drowns. In our photograph on page 2222 the kangaroo is standing in water four and a half feet deep, and it will be seen that the dogs are swimming around, not *at* him. When lassoed and brought ashore the kangaroo proved to measure when standing erect over six feet in height, while the tail was over four feet long. The kangaroo, when alarmed, raises itself on the tips of its hind feet, supported by the tail, and so commands a wide view of the surrounding country.

The food of the typical kangaroo is pretty much that of the sheep, but as an adult eats as much as three or four full-grown sheep, kangaroos are being rapidly exterminated near all settlements.

The nursing habits have already been described, but it may be added that the young are sheltered in the pouch long after they have ceased to need the nursing care of the mother. A young kangaroo weighing three or four pounds will tumble into this unique retreat at the first sign of danger, and the mother will flee with her offspring in her pouch until she can no longer carry her burden. Then she will deposit her young one on the ground and scurry from it, not to desert it but to lead the hunter from her little one, returning to find the latter after she has thrown the pursuer out of the chase. The young kangaroo has meantime lain snugly hidden, with the same skill which distinguishes the fawn when the doe is absent.

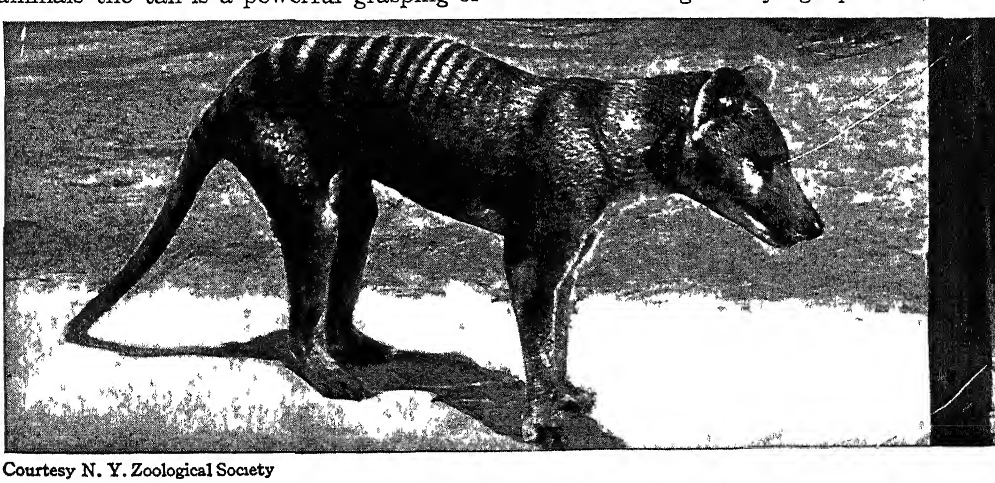
The wallabies do not differ greatly from their kin, the true kangaroos. They are smaller, of course, but vary considerably in size, some of them being no larger, when full grown, than a hare. While kangaroos frequent grass land and open forest, the wallabies affect the dense bush, though the rock-wallabies, as their name implies, are to be found only in rocky areas. The tree-kangaroos, which may now be studied in some large zoölogical gardens, are thought to have taken late in the story of evolution to an arboreal habitat since, though they leap with great boldness from considerable heights to the ground, they climb very laboriously. But the approximate equality as to length of fore and hind limbs shows that the transition cannot have been swiftly effected.

As we have marsupials resembling hares, so we have kangaroos closely resembling rats, some with furry, partly prehensile tails, some distinguished by brush tails. The place of these latter animals is taken in Tasmania by the jerboa kangaroo, a much larger animal, with the tail tuft scantily developed. All told, there are close upon two score species of the kangaroo and kangaroo-like animals, and the musk-kangaroo connects the remotest kin of the true kangaroo — the kangaroo-rat — with the extensive family of phalangers. Here we have no fewer than thirteen genera, embracing animals of surprisingly varied characteristics, yet agreeing in the thick, woolly nature of the coat, in the equal length of the limbs, and in the possession of a nailless toe or finger upon the hind foot, opposable to the other digits. With few exceptions the members of the family have long, prehensile tails.

In this family occur the so-called "flying" animals First to be noted is a shrew-like creature, the long-snouted phalanger, a true marsupial, yet in outline startlingly suggesting the form of our common little insectivore. This phalanger is an insectivore, too, and from its small mouth a long, sticky tongue is protruded at will for the capture of its prey. The cuscuses follow, animals of the size of cats, passing their lives in trees, where foliage is the main diet, supplemented by birds and other small living prey With these animals the tail is a powerful grasping organ, but in spite of its aid the cuscus, though purely arboreal, is a slow, if sure, climber. Like nearly all the marsupials, it is very tenacious of life. A kangaroo will escape with its chest gorged with blood from a bullet wound, or with its two hind legs broken; and the cuscus survives for hours even the breaking of the spine or a shot through the brain.

EMBODIED FEROCITY — THE TASMANIAN DEVIL

The Australian opossums are wrongly named; the true opossums are restricted to America, but there is no better title than that applied by the people of Australia; and the naturalist is driven to adopt it as a subtitle to the general name of "phalangers" which covers the whole. There are ten genera of these so-called opossums widely distributed over the Australasian region, and common to practically all forests and scrub lands. Here we have three groups of "flying" animals, allies of as many non-flying groups. The largest is the tanguan flying opossum, differ-

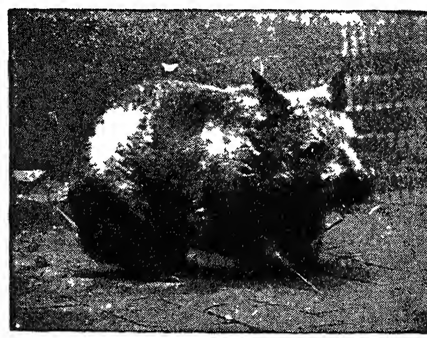


Courtesy N. Y. Zoological Society

A CARNIVOROUS MARSUPIAL — THE THYLACINE, OR TASMANIAN WOLF

ing from other opossums only in respect to the membranous parachute by means of which it makes the flight already described. This animal measures twenty inches from the tip of the muzzle to the root of the tail, but the flying marsupials range through many sizes down to that of the pygmy flying opossum, whose body-length is only a little over two inches, while a median position is occupied by the "sugar-squirrel", as the squirrel flying opossum is called in Australia. This expert little aëronaut has a body-length of some nine inches. The animal is described as making enormous flights through the air from tree to tree, and protecting itself from shock, when compelled to touch ground, by a slight upward swoop at the end of the flight immediately before alighting. Its diet consists of leaves and buds and insects. There is one flying opossum, however, Leadbetter's, which performs its aërial leaps without the aid of a parachute; and this animal, it is thought, is a representative of the parent form from which the opossums with flight membranes developed. The pen-tailed opossum "flies", too, without a parachute, and is regarded as the descendant of the form from which the pygmy flying opossum is derived.


THE RABBIT-EARED BANDICOOT


THE HAIRY-NOSED WOMBAT

The koala, or native bear, is the one phalanger lacking a long tail. In general outline it may be held to suggest its ursine namesake, but modern opinion inclines to regard this curious animal as a primitive form of wombat. In size it certainly agrees with the wombat, having rather the dimensions of a large poodle than that of even a quite small bear. Although mainly arboreal in habit, the koala descends at night to dig for roots, though its diet consists in the main of leaves. A curious feature of this animal is the cheek pouches which it has developed for the storage of food, processes resembling those of monkeys and certain rodents. In carrying its young upon its back, however, it has a point in common with the true opossum, though with the difference that the young opossum coils its tail round that of its dam.

The wombat more nearly resembles the bear than does the native bear. Squat, powerfully built animals, the wombats might readily be mistaken for diminutive bears, but on closer examination it is found that in point of dentition they approximate more closely to the rodents. They are exclusively herbivorous; the stress of life has driven them to burrow underground for safe homes, and they are nocturnal. The bandicoots are one of the plagues of the farmer, in eating seeds, bulbs and roots. The majority of them dwell in holes in the earth; some make nests, as does the pig-footed bandicoot.

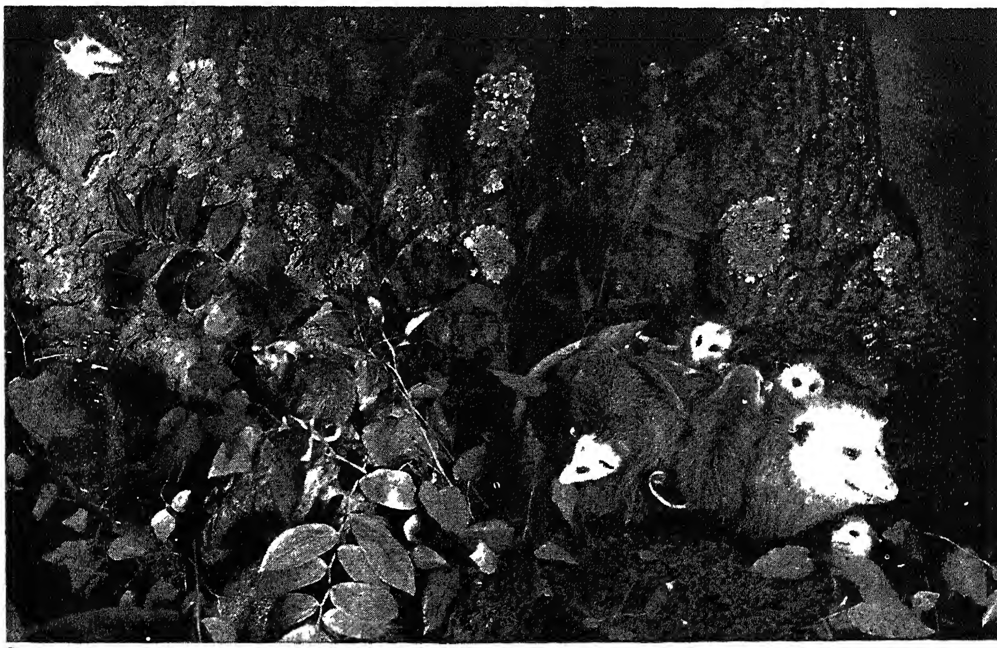
Turning to the carnivorous marsupials, we reach stupidity and ferocity embodied in the thylacine, or Tasmanian wolf. Though superficially resembling the true wolf, it is in reality infinitely removed from actual relationship. We have here a good example of parallelism, not relationship. The general features of the carnivorous wolf common to both have been gradually and independently arrived at in the two different and completely separated stocks; and the appearance, ways and movements of the thylacine suggest that it is a kangaroo masquerading as a wolf.

Its rapacity, however, is not simulated; the Tasmanian wolf is the worst foe that the sheep-breeder has to fear, and relentless war is therefore waged upon it.

The Tasmanian devil runs the thylacine close in point of destructiveness and stupidity, and is unrivaled for vice and quarrelsomeness, hence its name. Matching a badger in size, it has the true plantigrade gait of the bear, is nocturnal and a burrower, though sometimes using a cave or cleft in the rocks for its home.

We must pass over the marsupial cats, which seem to take the place of the martens; and we can only mention the pouched mice, tree-haunting insect-eaters, which appear to take the place of the tree-shrews. Like the true mice they are more prolific than other animals. The banded ant-eater is a marsupial lacking the external pouch. The young are attached at birth to the teats of their dam, and lie concealed among the dense fur with which the abdomen is clad. This curious animal has an extremely elongated muzzle, a long, worm-like tongue resembling that of the true ant-eater and, like that animal, depends for its food upon ants and termites. Moles are represented by the pouched mole, of habits akin to those of the true moles. With apparently sightless dots, deep-set in the skin, for eyes, this animal is equipped with a definite arrangement of cells upon the skin of the head, on the rump, and on the pouch; and these cells are believed to act as a sense-organ of touch, as compensation for loss of sight.

The only marsupials remaining in the world beyond Australasia are the selvas of tropical America and the opossums of Central and South America, with one species of the opossum ranging north as far as the United States. All possess a grasping organ of great sensitiveness and strength in the tail; all are arboreal in so far as a resting place is concerned; and all are nocturnal. Those which lack the marsupial pouch carry their young at first simply attached to the teats. Later the little ones are transferred to the back of the mother and it is an object lesson in adaptability to see the female opossum, high above the ground, with perhaps a dozen little ones riding on her back, their tiny tails clinging like creepers to hers, and their little paws clutching her ample fur.

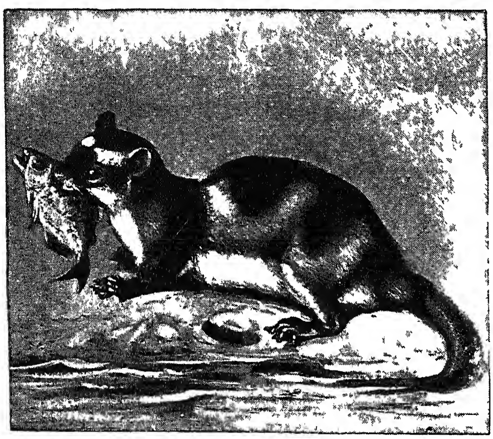


Courtesy American Museum of Natural History, N. Y.

FEMALE OPOSSUM WITH HER FAMILY

The best known of the family is the Virginian opossum, ranging from Argentina and Paraguay to New York, and a famous deceiver. This animal attains a body-length of twenty-two inches, and the tail is fifteen inches. One species of opossum in Argentina has taken to life on the treeless plains, the notable exception to the rule as to the arboreal habits of the genus. This is the yapock, already noted. It lives upon small fishes, crustaceans and the like; and, the better to qualify for an aquatic existence, has developed webbed feet, and in general habits is a remarkably close imitation of the otter.

The most familiar of these animals, however, and the one to which the name was originally applied, from the language



THE YAPOCK, OR WATER-OPOSSUM

of the Virginia Indians, is the common opossum (*Didelphys virginiana*) of the southern United States. It is also found generally throughout Central and South America.

It has a body about the size of a cat, a head with a long, pointed snout full of sharp teeth, small ears, a long, almost naked, prehensile tail, and a coat of thin, scraggy, gray hair. Opossums spend most of their time in trees, where they dwell in hollows, or in decayed stumps, hollow logs, or even dens underground; but they do not dig burrows for themselves. Their dens are comfortably bedded with leaves and dead grass, and there six to twelve young are born to every undisturbed pair two or three times a year. This unusual fecundity is one explanation of the survival of the race since Mesozoic times, for it is the prey of every predatory animal in its habitat, and as it gathers its own food not only in trees but on the ground, where it is a wide wanderer, it is exposed to many dangers. Opossums are themselves nearly omnivorous, eating fruit, mushrooms and other vegetable matter, and hunting for the eggs and young of birds, pouncing on wild fowl and rabbits at night, and searching chicken-coops, smokehouses, granaries and even farm kitchens with surprising boldness. They are, indeed, reckless in their thievery. "They will catch a grown hen and drag her off squalling at the top of her voice," says Lincecum, "and will not abandon her until the dogs which have been aroused by the uproar have overtaken and begun cracking their bones."

Often when this animal, or any of its tropical relatives, finds itself cornered or attacked, it will suddenly fall limp and apparently dead; and when the opossum "plays 'possum" he invariably draws back his gums from glittering teeth until he looks as if he had been dead a month. You may roll him about with your foot, or pick him up by his tail, or offer him any indignity and pain you please, and he will keep his pose; but turn your back, and he is likely suddenly to spring up and run away, and he is likely at any time to wake up and bite your hand if he sees a favorable chance.

Ordinary folks have taken this act for what it seems, and call it an instinctive feigning of death. They reject all theories of "paralysis by fear", when they know the animal well. It is to be noted, however, that this ruse is not always resorted to. When an opossum has a fair chance he will fight — especially in the case of a mother defending her young; and it shows a courage and ferocity in the use of its teeth that few animals care to meet face to face. Furthermore, the ruse is not always a safeguard, since many animals will seize a "fooling" opossum just as quickly as a living one. The artifice seems to be a vestige of some very ancient habit of defense not now so effective as formerly.

WHAT BRAIN STUDY SHOWS

The Astonishing Foldings of the Brain and the Activities that are Traced to Each

THE SWITCH BOARD THAT LINKS UP THE MIND

IF we weigh the entire brain, we find that the comparatively new development, called the cerebrum or great brain, comprises six-sevenths of the total weight. Of all this substance, however, only the much-folded surface really concerns us. As regards the folding of this bark or cortex of the cerebrum, we observe that it enables the cortex to have really no less than five times the area of the cerebrum taken as a whole. No wonder, therefore, that there is some relation between the degree of folding in different brains and the quality of their manifestations. But it is also to be noted that this method of folding the cortex is much better than merely thickening it would have been. Keeping the cortex thin, and folding it, had the advantage of enabling the nerves to get at it readily on its inner surface, and of enabling the tiny, innumerable blood-vessels from the innermost of the brain coverings to reach the cortex liberally and easily from its outer surface. It is to be remembered that the innermost brain membrane, the *pia mater*, dips into the fissures of the cerebrum, and thus follows the cortex in all its foldings.

Though every brain differs in the very small details of its surface pattern, yet the main unfoldings of the cortex are fixed in mankind, and are unfailingly transmitted by heredity in all normal brains, in every race everywhere. It thus becomes possible to prepare an average or constant map of the cortex, showing its division into a small number of lobes, having deep and constant fissures between them, and showing how each of these lobes is itself fissured, on the whole, in a constant way. Such a map of the left side of the cerebrum is shown on page 2093, with the frontal, parietal, temporal and occipital lobes clearly displayed. Each of these lobes corresponds, roughly, to the similarly named bones of the skull, shown on page 923. The importance of this preliminary mapping out of the cortex is extreme, for once we have gone so far, and find how constant are its main features, we find ourselves asking again the perfectly reasonable questions which were asked by Dr. Gall, the founder of phrenology, such a long time ago, and to which, in the state of knowledge at that time, only erroneous answers could be made.

In a word, we feel assured that there must be, in the brain as everywhere else in the body of man, or of any living creature, some correspondence between structure and function. May we not, for instance, be able to show that the occipital lobe is concerned with, say, vision, the temporal lobe with hearing, and so on? This is the great problem of what is now known as "cerebral localization", the attempt to localize the performance of certain functions in certain fixed and identifiable parts of the cortex. For this purpose we must, of course, consider the whole cortex, not only the outer surface, as shown in the illustration, but also its inner surface, which we see when we part the two hemispheres of the cerebrum, and look between them.

Our inquiries exceed in importance, for practical purposes in medicine and surgery, almost any that can be named, and for philosophy they far transcend anything else that science can attempt.

Their practical value is that, when a man suffers from particular disturbances of vision, say, or from a particular paralysis of a leg, we may be able, by means of cerebral localization, to infer that a particular area of his brain is being disturbed. No external sign whatever will be present, yet the surgeon will be justified in removing a portion of the skull, which he knows to be just over a certain area of the cortex, and he may then find a tumor, an abnormal thickening of bone or of the membranes of the brain, or even some parasitic invasion, which he can remove, thus curing or greatly relieving his patient. One of the greatest surgeons in this field was Sir Victor Horsley, who died July 16, 1916 His researches upon brain localization were among the most valuable of the many which have now placed this important subject on a firm foundation

Incomparable importance for philosophy of these researches in brain localization

As for philosophy, clearly no researches in the sky, nor in the rocks, nor within the atom can compare for a moment with researches into the functions of those particular combinations of atoms and molecules which constitute the cortex of the human brain, and serve as the organ of the human mind. The mind of man is so much the highest thing we know that nothing else is to be named beside it; our supreme questions, of God and Immortality, center in the mind or the soul of man; and the *cortex cerebri* is its instrument, so much so that if we crush it, or poison it, or destroy certain areas with a pistol shot, there is the earthly end of the soul. Evidently, nothing with which science can concern herself compares for a moment with the *cortex cerebri.* And in the nineteenth century science won amazing successes in this field, definitely localizing certain functions of the mind in certain sharply limited areas of the cortex; so much so that the doctrine called materialism seemed to be triumphantly vindicated, and the brain was said to secrete thought "as the liver secretes bile". Plainly we must now look into this with the utmost scrutiny.

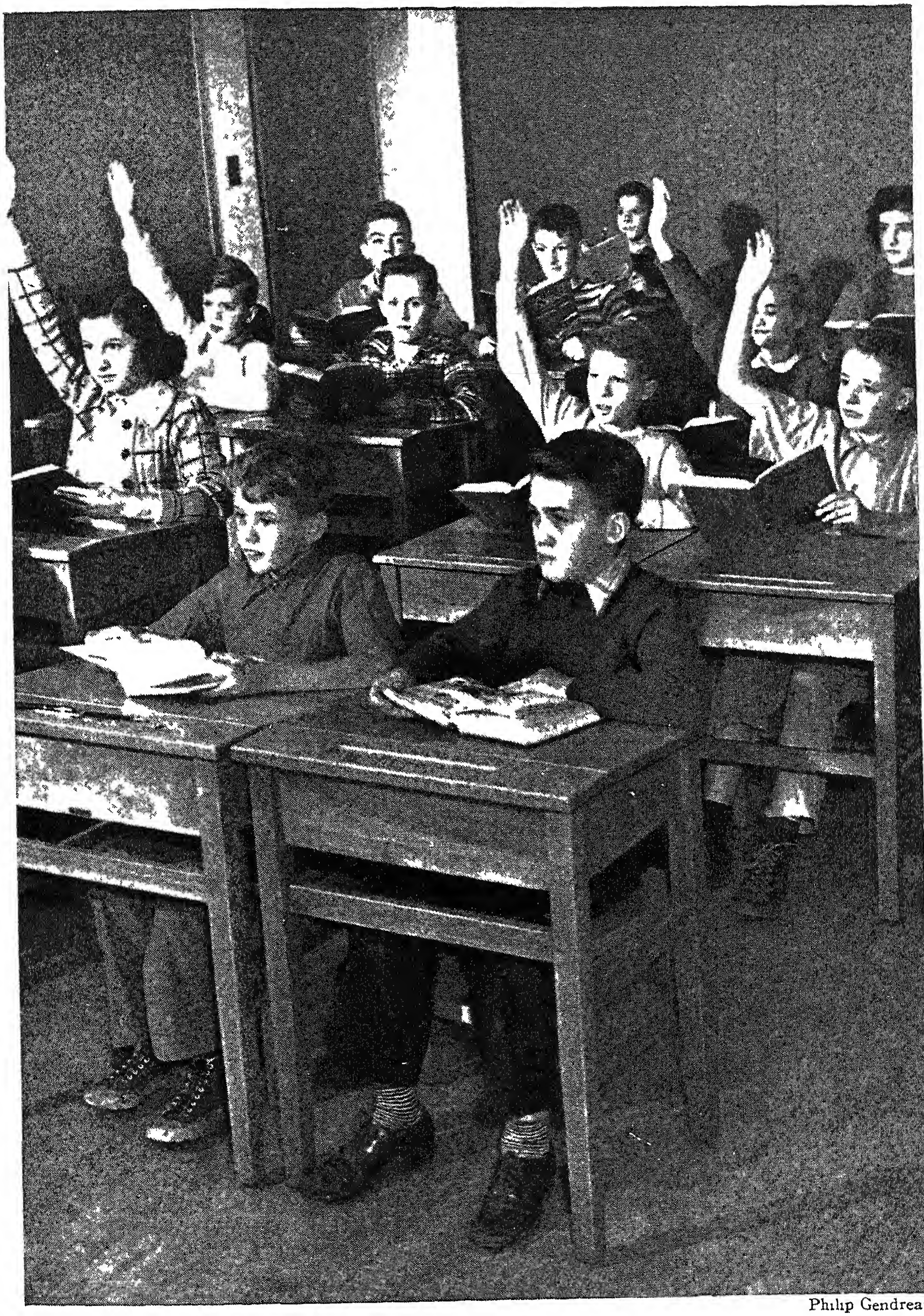
The relation between the brain and the power of speech

The famous French anthropologist Broca began by finding that destruction of a certain small area of the cortex in the frontal lobe of the cerebrum on the left side resulted in entire loss of the memory of words in a right-handed person. Thus we now speak of "Broca's convolution" and of the "speech center". We know, also, that the speech center is always to be found in the "leading half" of the brain — that is to say, the right half in a left-handed person, and vice versa. (We remember that there is no puzzle here, for the fibers from the cortex cross over in the lowest part of the brain, on their way to the body, and thus either half of the brain corresponds to the opposite half of the body) We know, further, that if the speech center be damaged in very early life, say, at three or four years, it is not a very difficult matter to make a fresh start, and teach the undamaged area in the right half of the brain, if the child be right-handed, and the damage has been done on the left side of the brain. But in later life, when the rupture or blockage of a blood-vessel has destroyed the action of the speech center, and, as often happens, has also paralyzed more or less of the right half of the body (in a right-handed person this would be), we find that the attempt to educate the corresponding area on the right side of the brain is almost hopeless. A few words may remain, having been learned by both sides of the brain, but they will be very few — as a rule only "yes" and "no" and other simple terms which have become largely mechanical.

The brain center for written speech not the same as for spoken speech

If we ask why speech or language should be specially associated with this particular area of the cortex and no other, we simply find that this is the area which corresponds best to the movements of the tongue, lips and jaws and palate, that are concerned in speech. In other words, it is only spoken speech that is represented here, and we must look elsewhere, though not

YOUNG MINDS AT WORK



Philip Gendreau

The brains of these bright youngsters are actively functioning. The teacher's words have been transmitted by way of the internal ear to the temporal lobes These words, as the eagerly raised hands indicate, have aroused responses in the association areas, which are found in the cerebral cortex.

far, for written speech. We find, also, that where more languages than one are spoken, each language appears probably to have a little area of the cortex to itself. But, indeed, many a large volume is devoted wholly to the speech functions of the cortex, and we can go no further into the more dubious matters here. Yet we have already noted a fact which leads us far — that the motions of certain parts of the body are represented in the cortex. Naturally the inquiry proceeds with this clue, and we soon find that *voluntary* motions of all parts of the body are sharply and constantly represented in the cortex. The "motor centers" are found on the outer side of the brain, grouped just anterior to the deep and constant "fissure of Rolando", so that this is often called the "Rolandic area", including only part of the frontal lobe, in front of that fissure.

The motor areas of the cortex used for coördinating groups of muscles

But we must no longer call this the motor center or area, for the brain and the spinal cord have many other motor centers and areas, and motions of all the voluntary muscles in the body can be initiated without invoking any part of the cortex at all. The cortex is a new formation, and it stands for will and purpose. The only proper name of this area is not motor but psycho-motor, to indicate its real status.

We might suppose that such a great muscle as, say, the biceps of the arm would be represented in this area, but we are wrong. The biceps, and every other muscle, has a nerve supply which can be traced to definite centers in the brain or spinal cord, but no muscle whatever is represented in the cortex. The psycho-motor area of the cortex is concerned not with individual muscles, but with coördinated and balanced groups of muscles, urged as a whole for the performance of definite, purposeful movements. The psycho-motor center is the controlling mechanism of a being who uses his body and its parts for purposes, and thus achieves them. It follows that you can voluntarily bend or extend your arm, or perform any other movement you please, but it is a physical impossibility for any man to stimulate his biceps, or any other single muscle, by means of his will. In fact, every willed movement involves not merely the stimulation of certain muscles to perform it, but also the stimulation, and sometimes the forbidding, of certain other muscles, which have the opposite action.

The cells that feel sensations and those that initiate voluntary movements

The balance of the whole, initiated in the cortex, and in the cortex alone, achieves the movement, and accomplishes the purpose, but it is only when we observe the results of disease, either of the cortex or of the centers below, which it controls and balances, that we realize how amazing and indispensable its functions are for movement that shall be anything but unmanageable spasm.

Further, as the photographs on pages 66 and 67 show, certain layers of the cortex in this region are characteristic, containing the very large pyramidal cells which are definitely associated with voluntary movements. But though those cells are characteristic of this area, being found nowhere else in the cortex, they do not comprise the whole thickness of the gray matter in this region. There is something else to reckon with, and that is what we call "common sensation".

The cortical center for common sensation — the sensations of touch, temperature and pain being included in that term — was long sought in vain, until at last the localizers found that it coincides with the Rolandic area. In other words, this is a *sensory motor area*, in which, cheek by jowl, and in the most intimate relation by means of their "dendrites", are found both the cells which feel these sensations derived from the skin, and the cells which initiate voluntary movement. Thus the machinery suits the need, as when, for instance, we remove the hand from a hot surface, or return the hand to a pleasant surface, the sensation and the corresponding movement have their seat in almost the same area of the brain. The motor area is just in front of the fissure of Rolando; the sensory area is just behind it.

The size of the motor-areas in relation to the complexity of movement

But though this area is large, it only comprises a small fraction of the whole cortex, and there is much more yet to account for, though we cannot leave the Rolandic area finally without noting the results of comparative research in many animals — that the size of the area for any particular movement is proportional to the complexity of that movement. Thus the arm and hand of the ape have far larger cortical representation than has the foreleg of the dog, though the muscles are equal in size in the two cases. And in no other brain is there anything parallel to the liberal cortical area which, in the brain of man, corresponds to his hand, and, above all, to his thumb. But we must pass on, for though we have localized voluntary movement and common sensation, which are certainly paramount, vision and hearing, to mention nothing else, remain. Here, as in the localization of common sensation, we owe much to the classical researches of the great Scottish investigator, David Ferrier.

We now know that the cortical center for hearing is in part of the temporal lobe. But again there is crossing over of the nerve fibers, so that the cortical center for the right ear is in the left temporal lobe or vice versa. Here complications are endless.

The areas of hearing and understanding are neighbors, but not the same

Hearing is one thing and understanding is quite another. We find that there is a cortical center of sheer hearing, but that there is another, adjacent but distinct, in which reposes our appreciation of the meaning of words. Often we hear and say, "Beg pardon!" not having really attended, and then, a little later, we understand. In the first stage, the hearing center was at work; in the second stage, the understanding center also came into action. Similar complications to what we have already seen also arise here in relation to the understanding of different languages — not least of the "universal language", which is music.

Probability of a definite music center

It is very probable that there is a quite definite music center, close to, and presumably a specialized part of, the ordinary hearing center. But here, as in many other problems of cerebral localization, we shall never get much further until critical comparison has been made of the brains of musical, non-musical, and tone-deaf persons, as well as of great composers. For this purpose, as for many others, science requires the state of public opinion and cultivated altruism which has already induced a very few distinguished men to bequeath their brains for the purpose of science.

How the real eyes of every man are in the back of his head

Meanwhile, we must proceed to the case of vision. Here the cortical area is found to be in the occipital lobe of the brain, and at its furthest back portion; so that the real eyes of every man are in the back of his head. A tumor growing in our occipital lobes will gradually cause blindness even though our eyes are apparently perfect. And in this instance, as in others, comparative anatomy shows how vision has been promoted, asked to go up higher, in the course of organic evolution. Even among insects, which have no real brain, we find large collections of nervous matter, which we call optic lobes, and which are associated with vision. In the brain of the fish the biggest structures are such optic centers. But when the cerebrum develops, the center for vision is slowly transferred to it. In the lower mammals, this transference has partly occurred, but even such a high mammal as the dog has not the whole of its vision-center transferred to its cortex. In the anthropoid apes and in man, however, the transference is complete. We see with our cerebral cortex alone. All the older structures remain at the base of the brain, and the nerves from the eyes visit them; but they only survive for old sake's sake, so to speak, and the cortex has taken over all their functions, and discharges them a thousand fold better than ever before.

No sight of the lower animals compares in complexity with that of man

The reader may be inclined to measure vision in terms of ocular acuteness, and will naturally question the asserted visual supremacy of man over, say, the hawk, or many other animals. The real tests, however, are perception, comprehension, discrimination, memory, visual synthesis and symbolism, as in associating sounds and meanings with certain visual shapes, which we call reading; and here man is preëminently first. The visual area of his cortex has no animal parallel for extent, and for the variety of its cells.

When it comes to the sense of smell, however, man is found to be degenerate. This sense has its cortical representation on the inner aspect of the temporal lobe, which is only to be seen when the brain is parted down the middle. This area is as inferior in man to the corresponding area in the dog as the visual area in man is superior to that of the dog. The familiar facts of the sense of smell, in the two creatures respectively, correspond exactly to what we find in the study of the cortex. The dog lives largely in a smell world, man largely in a vision-world. In man, the sense of smell has long been decadent, simply because that of vision was found to be so immeasurably better worth development. Thus the dog only bays the moon, man has measured the altitude of its volcanoes; the dog has never noticed Sirius, and man knows its mass and chemistry. And we need only remind ourselves of the developments and possibilities of vision in terms of art and of geometry in order to understand why man may be content that his sense of smell, a mere contact chemical sense, and very rapidly fatigued into the bargain, so that we cease to smell in a few seconds, is decadent beyond repair. He had bargained well. As for the relatively trivial sense of taste, its cortical representation is not far from that of the sense of smell.

Having thus accounted for motion and sensation, we might suppose that the whole surface of the cerebrum would now be mapped out.

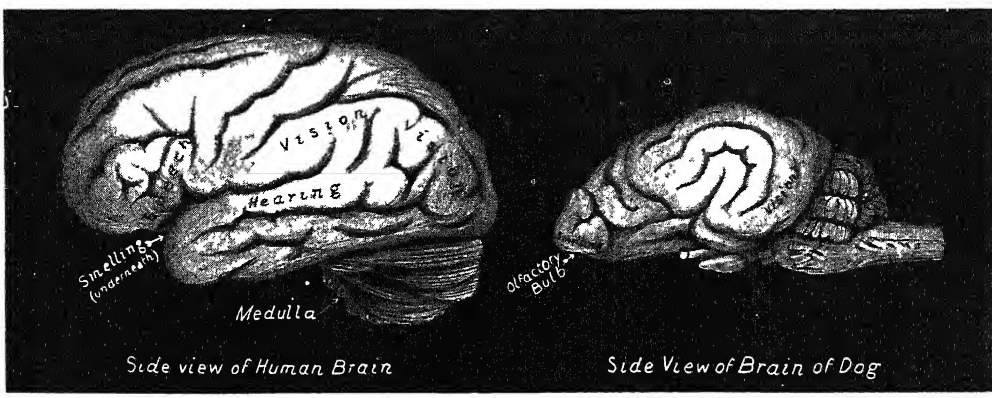
The silent areas of the brain and their probable concern with "association"

But that is immensely far from being the case. Even now, the greater part of the cortex remains unaccounted for, and we have no definite functions to seek a place for. Or, rather, we have all those functions which involve more than either sensation or motion, all the higher functions of intelligence. Primarily, these functions depend upon the power of association, or "putting two and two together". We may therefore suspect that association is the true function of those "silent areas" of the cortex, as they have been called, which yield no answer when we inquire of them, and produce no results when they are locally stimulated or irritated by disease or injury. Very important and suggestive facts are yielded by special study of these silent areas. The cortex here is no less thick, no less richly supplied with blood-vessels, no less abundant in nerve-cells, than elsewhere.

If we compare the brain of man with those of a series of the lower animals, and place them in the known order of intelligence, the results are found to be very striking indeed.

As intelligence, association, the power to put two and two together, or to *learn*, and find out, increases in the scale, so the cortical area as a whole increases; and certainly part of this increase is due to the fact that, for instance, the centers of vision and hearing grow larger. But the enlargement of the areas with known functions of motion or sensation only accounts for a small part of the total extension of the cortex with increasing intelligence. Much the greater part of the development is in these silent areas, which seem to have no functions at all. Indeed, the growth of the cortex, compared in an ascending series of brains, appears mainly to consist in a development of surface between the areas of sensation and motion, ever thrusting them further and further apart, so that in the lower brain they lie beside one another, and in the brain of man they are mere patches upon a chiefly unallotted surface.

This can only mean that, somehow or other, these areas are connected with the development of intelligence; and there is another piece of evidence. Dr. Hughlings Jackson taught that the nervous system consists of a series of levels, superimposed upon one another, the highest being the latest in order of evolution — a fact which we recognize when we speak of the cortex as the neo-pallium, or new mantle of the brain. We further observe that structures which have developed last in the history of the race also develop last in the history of the individual; and finally, that structures which were "last to come" in the history of the individual or the race are the "first to go" when the individual is being broken down by poison or old age. and highest parts, and we must trace the bundles of nerve fibers that proceed from them in order to see whether they perform the functions which we suspect At once we find that these fibers run to and terminate in *other parts* of the cortex and the brain in general, notably including the cerebellum. Further, we find strand upon strand of nerve fibers proceeding from the cells of the sensory areas to these silent areas, and ending among the cells there The evidence is therefore conclusive that these "silent areas" of the cortex, which are the most characteristic parts of the entire physical structure of man, are indeed association areas, and that they must be concerned in all those processes of examination, recognition and association of sensations, and



THE BRAINS OF MAN AND DOG COMPARED, SHOWING AREAS OF SMELL AND VISION

Observe now that these silent areas of the cortex show their comparative youth, even when compared with the rest of the new mantle itself. We have seen that, in the evolution of the race, they are the last to appear. So also is it in the evolution of the individual. These areas are last to come, as is proved by the fact that the nerve fibers running from the cells of these areas are the last in the whole nervous system to acquire the sheaths which isolate the nerve currents, as we suppose, and which must be formed before the nerves can perform their functions. Finally, in decadence of the individual, there is some evidence to show that these parts of the nervous system, last of all to come, are the first to go.

These unmapped areas of the cortex are therefore to be looked upon as its latest

the building up of mere crude sensations into true perceptions, which lie at the basis of all intelligence. It therefore becomes of high interest to trace these association fibers as closely as possible, and to see in what visible physical ways they bring the various definable areas of the cortex into relation.

The reader may possibly have been asking for a modern answer to the old question whether the frontal lobe is the seat of the intelligence, it being well known that the frontal lobe of the brain has a most remarkable development in man, as we recognize whenever we use such a phrase as "his noble forehead".

The answer is involved in the statements we have already presented. There is no lobe of the brain that is the seat of the intelligence.

The brain not dependent for its intelligence on any one lobe

The whole of the cortex is concerned in intelligence; and its efficiency for this purpose must depend, first, upon its unparalleled extent in man; second, upon the amazing perfection with which all the parts of the cortex are brought into close touch with each other by means of the association system of the cerebrum. That association system, which is the narrowest term of physical structure within which we can pretend especially to confine the intelligence, has its cortical centers all over the surface of the brain. True, the frontal lobe makes a very large contribution to the whole, and thus the close relation of the frontal lobe to intelligence cannot be denied. But exactly similar cortical centers of association are to be found, in wide extent, in the parietal lobes, for instance, and in all parts of the surface of each half of the cerebrum, both outer and inner. All these areas together must be reckoned the special seat of the intelligence, if we are to name as such anything less than the united, associated, exquisitely unified whole which we call the cortex cerebri.

The importance and number of the association fibers of the brain

That cortex is only about one-eighth of an inch in thickness. Its cellular contents have long been studied by the microscope, of which the latest and best results are shown photographically on pages 66 and 67 of this work. Nothing can be here added to what those photographs demonstrate. Only we can observe that every part of the cortex is connected, directly or indirectly, with every other by means of association fibers, both leaving it and coming to it. We find short association fibers that connect adjacent convolutions of the brain, and longer strands which run between the various lobes of either hemisphere. And we further find certain very numerous and conspicuous groups of association fibers, usually called commissural, which travel across from one cerebral hemisphere to the other. Most notable of all these, and of steadily increasing importance in the mammalian group of animals, culminating in man, is the *corpus callosum*, an almost numberless bundle of nerve fibers that have their origin in the various cortical areas of one or other hemisphere, and are traveling to the opposite hemisphere, there to end somewhere around the bodies of its cortical nerve cells.

So much, then, for the physical structure of the cortex. We may pursue the details indefinitely, always tracing the nerve fiber from its various areas more and more accurately, and we may expect, by refined methods, to see more and more detail of its nerve cells. There is also an infinite field for study in the comparison of the cortex of different brains, first as regards different races, but above all as regards the special powers of exceptional individuals.

The true relation between animal mechanisms and the human will

In this direction it is just to say that at present we know nothing, and that there must surely be most important and remarkable results to obtain when opportunity offers. But no matter how perfect our methods, nor how many brains of common people and men of genius and lunatics of all races we examine, the cortex cerebri will never yield us more than the physical structures which we already know. Nerve cells and their processes are the beginning and the end of the story.

It only remains for us to try to interpret the functions of the human cortex cerebri in terms of what we observe in the behavior and personal conduct of man. We must cease to suppose that, under the microscope, we shall ever find mind visible, for that is to misunderstand the nature of mind. But we may certainly try to express the true and characteristic functions of the cortex as the supreme organ of mind.

In all the levels and parts of the nervous system, below the cortex itself, there exists the apparatus for a number of motor mechanisms, as, for instance, swallowing and walking, which are either ready made, or easily put together in the developing nervous system, and which at a signal, will always set to work and perform the particular act which corresponds to them.

The will is employed, sometimes in constructing the mechanism, as when we learn to walk or play the piano, and at all times in choosing the mechanisms to be used, the manner of combining them, and the moment of their employment.

The back of the brain the switchboard of the sensation

From this point of view, then, which is concerned with the cortex in relation to action, we may compare it to a switchboard, where all the paths of sensations, and all the paths of possible movements, cross, and can be connected. We have already seen that, first by means of its allottable areas, where all sensations and movements are represented, and then by means of its association areas, the cortex of the human brain answers beyond all imagining to this idea of an incomparably complicated switchboard, the ruler of which, the will, can use it for each and every purpose. This cortex is the switchboard of a creature who is, above all, a center of action. The nervous system beneath the switchboard marks out the possible lines along which action can run.

But there is choice between them, and above all is there choice in the case of man. Choice and consciousness go together — the greater and more real the choice, the more intense the consciousness; and since man has the amount of choice represented by the amazing possibilities of the switchboard we call his cortex, consciousness reaches a unique intensity in him. Thus it looks, at first, as if consciousness flowed from the cortex, but that is a false statement of the relation between them, which Henri Bergson has thus most admirably stated:

"In reality, consciousness does not spring from the brain, but brain (*i.e.*, cortex) and consciousness correspond because equally they measure, the one by the complexity of its structure the other by the intensity of its awareness, the quantity of *choice* that the living being has at its disposal."

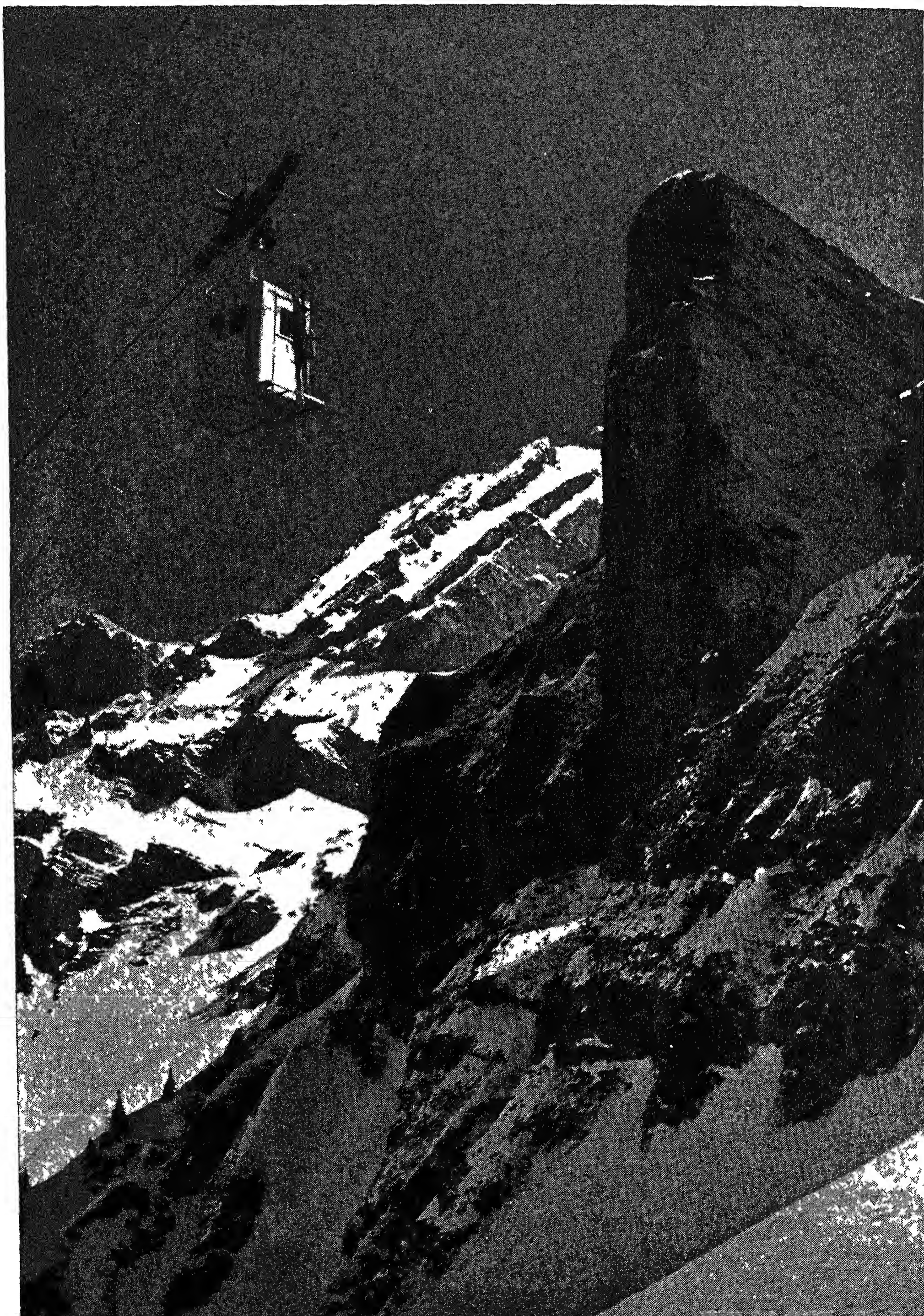
In all these associated respects man is unique. The difference between his brain and even that of the anthropoid ape is such that it is really a difference of kind. Up to and including the ape, the cortex of the brain has never been able to do more than set up a limited number of motor mechanisms, according to the structure of the creature's body and nervous system and then it chooses between them.

But the brain of man differs in that its power of constructing machinery for action is not limited to the body underneath the brain, but can transcend it. Man can make tools — pianos, airplanes, pen and ink — outside his own body, and then his will, using his incomparable cortex as its switchboard, can choose among them. In all other creatures the choice is limited; in man it is unlimited. This is the difference between the closed and the open, a difference not of degree but of kind.

Mind always aims at freedom within and empire over the physical, which it uses as its instrument, and in which it is displayed. In man alone does this freedom realize itself, thanks to his cortex, which enables him to construct, within and without his body, an unlimited number of mechanisms, not least the mechanism of articulate speech, between which his will can choose, and in choosing and using which his consciousness is manifested — his life becomes aware of itself.

Man's mind the only open road of progress that remains

Everywhere but in man consciousness has had to come to a stand; in man alone it has kept on its way. He alone continues indefinitely forward the eternal thrust of life; in him alone the will, which is of the very essence of life, becomes free. This is not exactly to assert "the freedom of the will", which has yet to be studied, but it asserts that the "will to live", which we now see to be the will that is part of all life, has found and made in man alone the open road. Such is the conclusion which we reach at the end of our study of his body from the physical side; and it warrants us in now passing, more humbly and more proudly, to the study of the "human mind", which is Mind as the ultimate psychic substance of life, clearly evident in humbler forms, but transcendent in man.



E. Gyger

This aerial railway between Adelboden and the Engstligen Alp, in Switzerland's Bernese Alps, bears skiers up to the top of the skiing slope. They will make the return trip on their own power!

MOUNTAIN AND AERIAL RAILROADS

The Stupendous Engineering Employed to Enable Trains to Climb Continental Divides

OVERCOMING "INSURMOUNTABLE" OBSTACLES

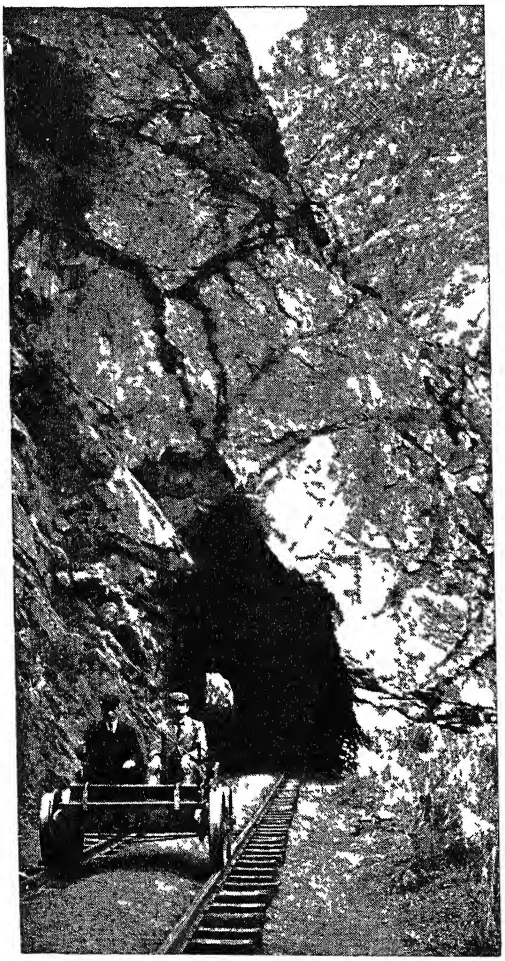
IN surveying for railroads, while a straight line may be the shortest distance between two points it is seldom the easiest path to follow, and this latter fact is responsible for the horseshoe curves and hair-pin loops in railroad lines that are found in hilly and mountainous country. There are cases in which a tunnel through a mountain has proved to be the cheapest as well as the shortest way in which to overcome the obstacle, but when costs and probable traffic are considered, the final choice for the road-bed will usually be around instead of through or over the mountain, so that often a long curve in the line was not put in for the convenience of the towns through which the road runs, but because it was easier and cheaper to go several miles out of the straight path rather than make the locomotives haul heavy loads up a steep grade. Decreasing the grade means increasing the trackage, and sometimes tunnels as well, to make possible the approach. With the advent of the electric locomotive, steeper grades can be climbed than with the most powerful of steam-driven engines.

Of all the engineering works of man a great mountain railroad, with its curves, loops, tunnels, trestles and bridges, is the most inspiring. Here the tracks are laid through a deep gorge, blasted by dynamite from the solid rock; there they cling to the side of a precipice with its walls towering a thousand feet above and below the road-bed: at one point they cross a valley on a stilt-like trestle hundreds of feet above the ground, at another they slink out of sight into a dark hole in the side of a mountain, to emerge again perhaps several miles away. The ingenuity of the world's greatest engineers is taxed to the utmost by the problems offered when man determines to reach the other side of a mountain range with his iron steed. When a hill and a valley threaten to trouble him he blows up the hill with dynamite or nitroglycerin and fills up the valley with what once was the hill. Sheer walls in the path of the engineer, with no possibility of circumvention, delay but do not stop him, for if he can find a foothold, there he will lay his rails, and laugh in triumph at nature's defeat.

Many mountain railroads are short, and were built for the benefit of tourists. Generally these climb the sides of the mountains, but in order to avoid thus defacing the beauty of one mountain, the engineers dug a tunnel to the top, and the trains crawl through a lighted tube in the granite heart of the monarch of the Oberland. But the highest mountain railroad in the world was built for traffic, and on a purely commercial basis.

In 1870 an American contractor, Henry Meiggs (1811-1877), began the line over the Andes in Peru, part of the plan to connect the Pacific Coast of South America with the markets of the Old World. At that time the Peruvians were very prosperous. Guano in enormous deposits was being exploited on the islands off the coast, and an abundance of nitrates had been discovered on the mainland. Fortunes were being made, and with huge loans negotiated by the Peruvian government, a period of railroad building was begun which resulted in the amazingly audacious line from Callao to Oroya.

Meiggs proposed to start at the former, which is a very important seaport, climb to the crest of the Andes, drop down to the highlands on the other side, and cross the plateau until a point was reached on the Amazon to which Atlantic steamships could come. It was figured that in this way the voyage around Cape Horn would be avoided and that Peru



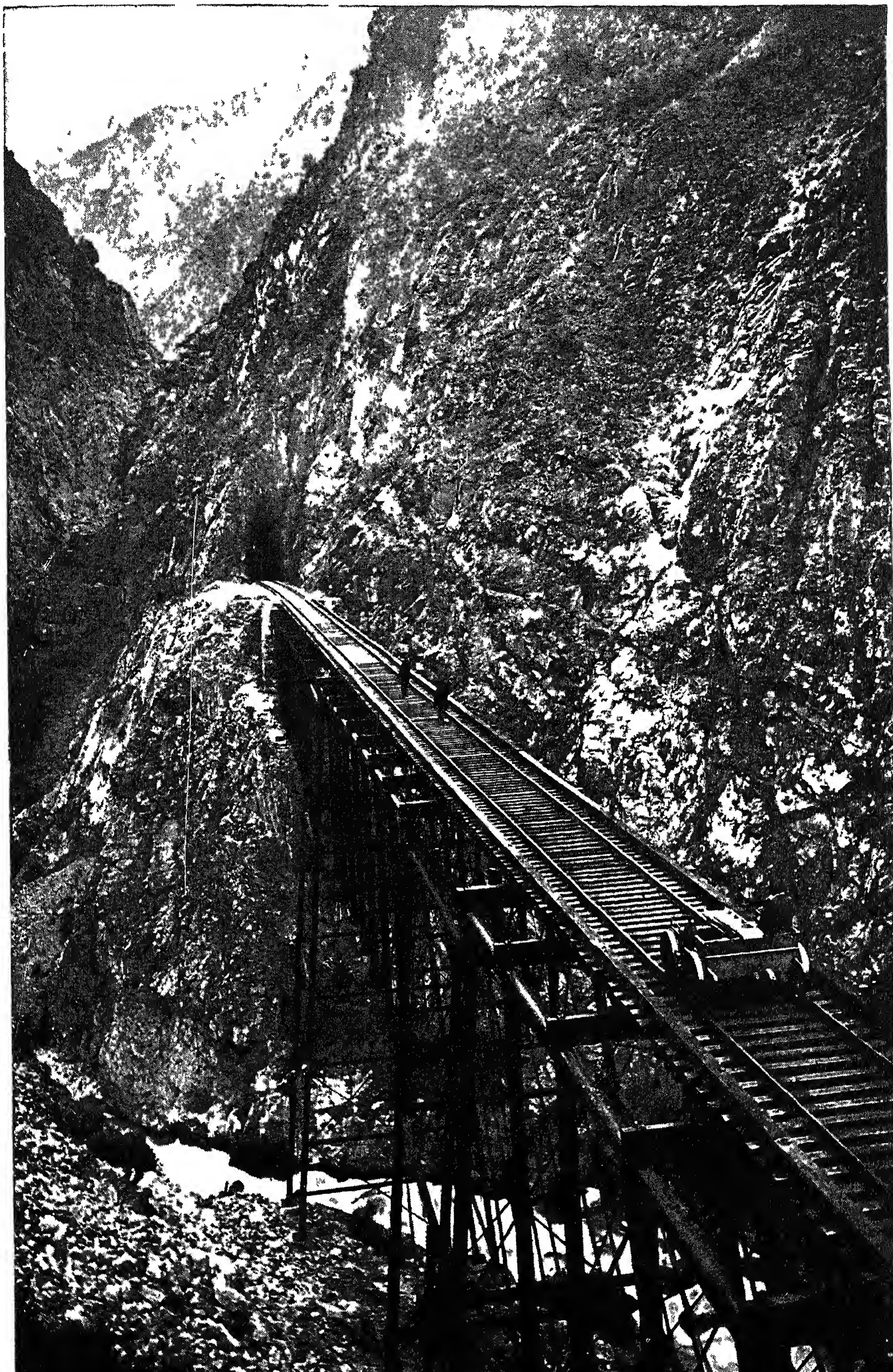
COASTING FOR 100 MILES FROM SNOWCLAD MOUNTAIN TO TROPICAL VALLEY ON THE OROYA RAILWAY

would become the chief center of commerce on the southern Pacific Coast.

Unfortunately the financial strength of Peru was later so undermined by internal and interstate disorders that only one section of the proposed road was ever constructed. This section, however, is a triumph of engineering genius, and stands as the railroad wonder of the world. Although by air-line the distance covered is about 80 miles, the line so twists and turns that nearly 150 miles of road-bed are required. The road pierces the Andes at 16,000 feet above sea level with a tunnel nearly a mile long, and in the descent from Ticlio, the highest railroad station in the world, to Lima there are 67 tunnels and over 65 trestles. It is possible to coast down on a hand-car, and the thrill of speeding through tunnels in pitch darkness and over trestles 300 feet above the ground at a speed of 60 miles an hour or more can well be imagined. The beauties of the Andes are great, but many who have viewed them from the Oroya Railroad will never wish to do so again, for their experience with mountain sickness or "soroche" has taken all pleasant memories from the trip. In a few hours the traveler is carried from the tropics to a region of eternal snow; from a level at Lima where the atmospheric pressure is 15 pounds to the square inch, to one at Oroya where it is only 10. The effort to supply the lungs with the rarefied air, and the trip-hammer beating of the heart are both depressing and dangerous.

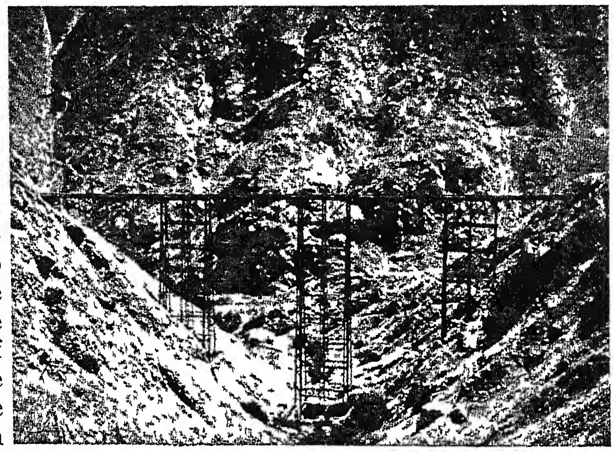
Meiggs followed the Rimac River into the mountains until it became so narrowed in a defile that the road-bed had to be hewn out of the solid walls of the gorge. The Verrugas and Infernillo bridges are the most notable crossings. At the latter point two walls of rock rise 1500 feet on either side of the river, and the trains cross from wall to wall, out of a tunnel on one into another tunnel on the other side At the site of the Verrugas bridge, 275 feet high and 6000 above sea level, Meiggs came near defeat. Until the bridge was built material for continuing the line could not be carried across the gorge Large gangs of workmen were put at the task to hurry it, when a strange and terrible endemic disease broke out. A form of wart (*verrugas* in Spanish), which is believed to have been one of the causes of the mortality from hemorrhages of the skin among the troops of Pizarro, caused great loss of life not only among the English workmen and engineers, but among the natives as well.

TUNNEL AND TRESTLE ON THE TRANSANDEAN



CHANPICHACA BRIDGE AND TUNNEL 9472 FEET ABOVE SEA LEVEL

Hundreds of men died, many within a few hours after reaching the site. Fabulous wages were offered in an attempt to get others who would brave the danger, for the fear of the pestilence threatened to stop the advance of the enterprise, and finally a band of hardy adventurers was assembled who at last spanned the gorge.



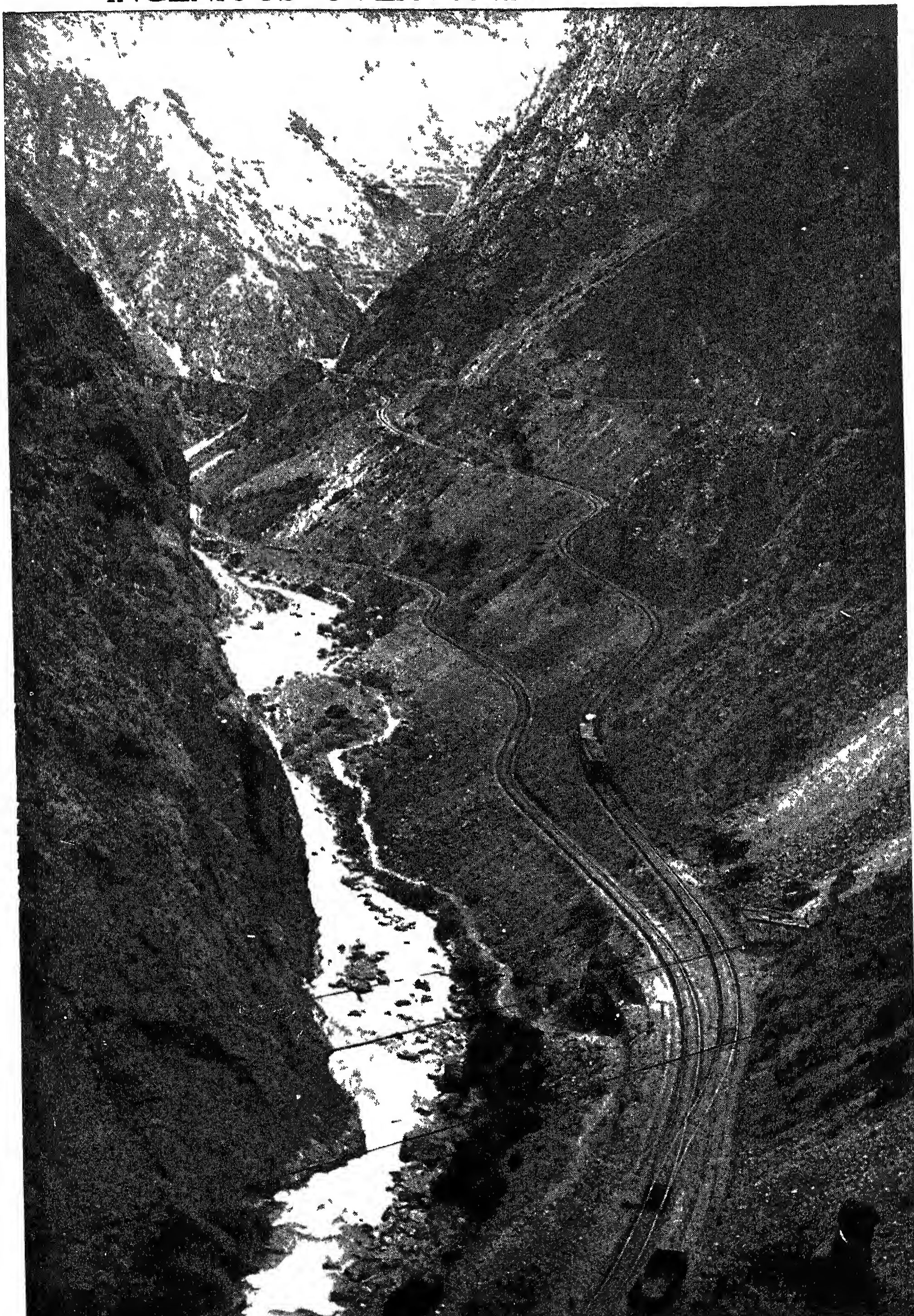
THE ILL-OMENED VERRUGAS VIADUCT ON THE OROYA RAILWAY, PERU

Meiggs himself escaped the plague, and holding resolutely to his plans, he plunged into the wildest regions of the Andes. The mountains rose like walls on either side, the ravines grew deeper and harder to span, and the slopes of the mountains were swept by frequent landslides. At the end of six years he had succeeded in rising to a height of over 12,000 feet and had built nearly 90 miles of road-bed. His terrible experiences and the rarefied air of the mountains breathed over this long period finally caused his death in 1877.

Two-thirds of the original plan was complete at his death, and the worst part of the line was finished, but fourteen years passed before any further advance was attempted. Another American engineer, William Thorndike, took up the work and carried it to its present state of completion. After rising nearly 3500 feet above the level to which Meiggs had brought the road-bed, a mountain faced him, over or around which there was no possible path. At an altitude of 16,000 feet his tunnel, over 3800 feet long, is the crown of the greatest of railroad enterprises. In the middle one stands on the Great Divide of South America.

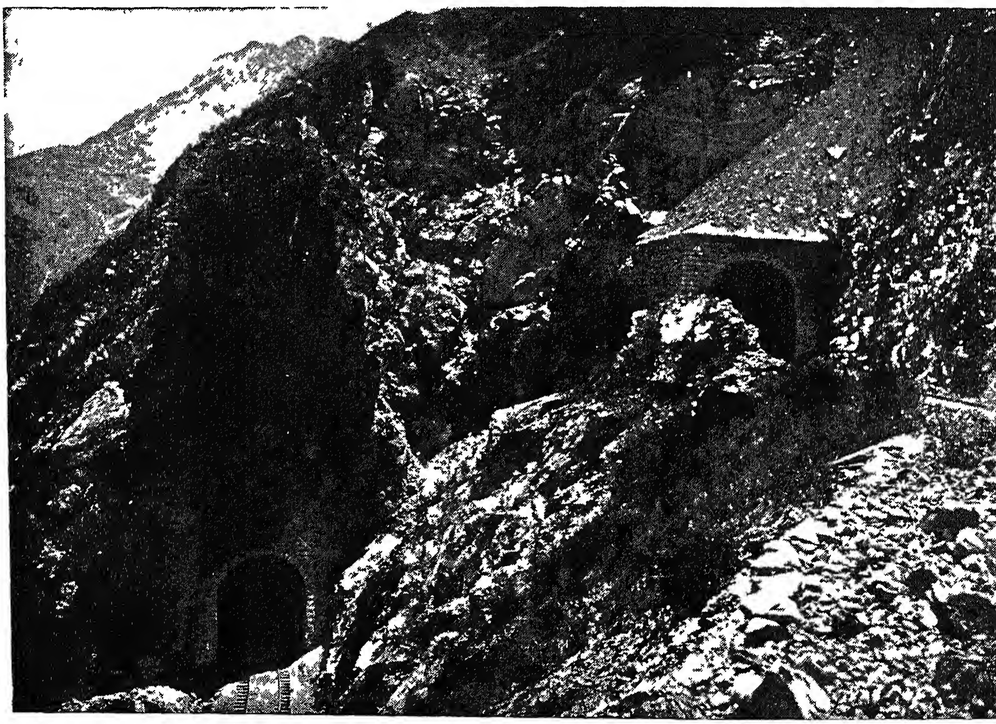
MEIGGS' V-SWITCH WITH A LOCOMOTIVE ON THE TURN-TABLE

Perhaps the most ingenious feature of the road is Meiggs' V-switch, by which he made possible the elimination of loops and tunnels for an approaching change in direction of the road-bed, and saved thousands of dollars. A ledge on which he was laying tracks came to an abrupt end. On one side the walls dropped sheer down into the valley below, on the other side the cliffs towered above him to an appalling height. Some feet above the ledge on which he was working was another leading back in the reverse direction. At the junction of these two he put in a V-track, with a turn-table at the open end of the V. The train runs out on to one leg of the V, the locomotive is uncoupled, turned on the turn-table, runs back on the other leg of the V, coupled to the other end of the train and pulls it back on the main line again. There are 17 of these V-switches in the mountains where reversal of direction is necessary. The cost of construction of the Oroya Railroad was over $40,000,000 — more than that of the famous St. Gothard, with its 172 miles of rails and its great tunnels, $9\frac{1}{4}$ miles long and costing alone about $13,000,000, under the Alps.



SWITCHBACK ON THE OROYA RAILROAD OF PERU

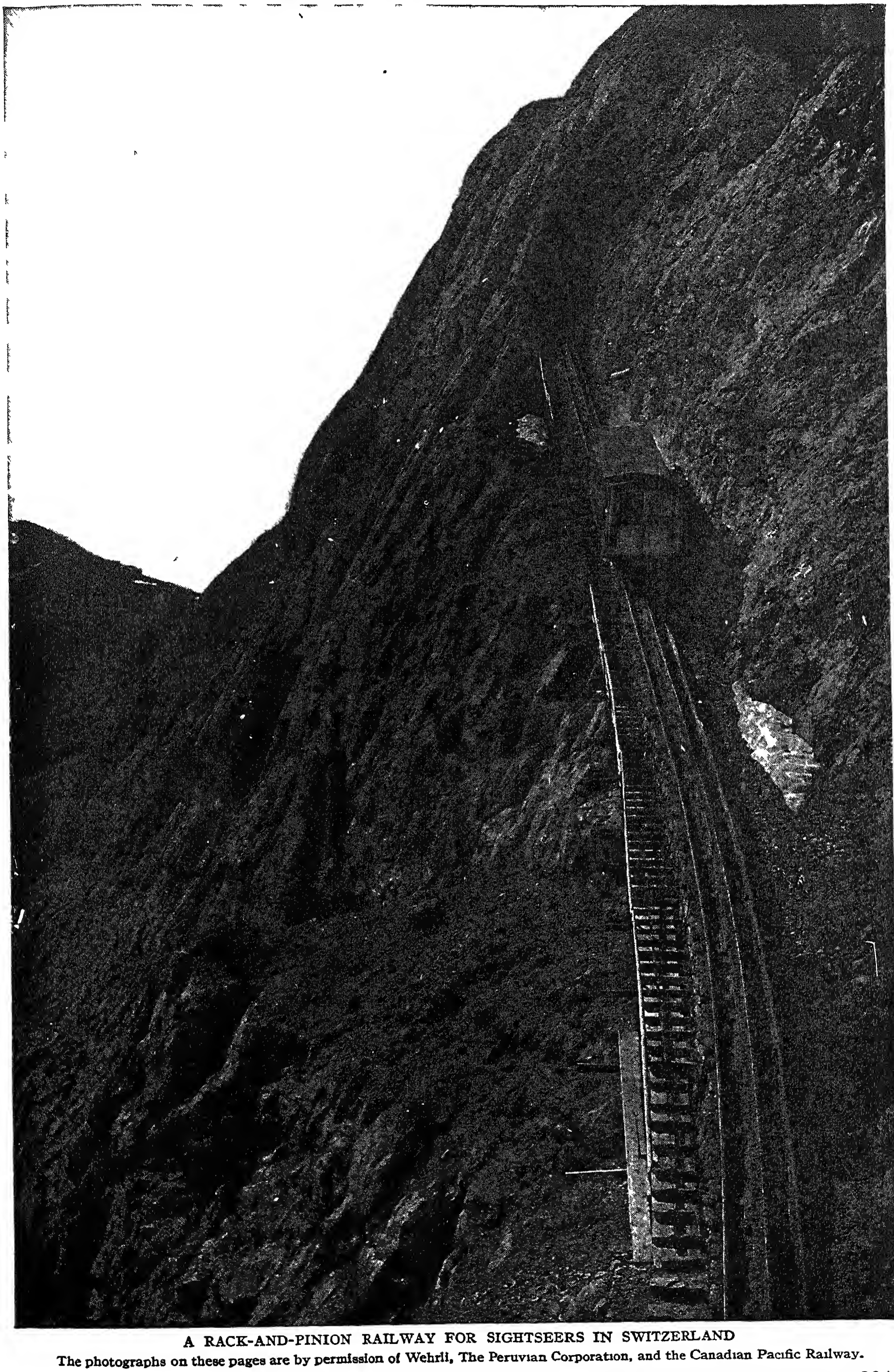
The Andes is crossed today by three other railroads. South of Oroya is a line 332 miles long, leading up to the great inland lake above the clouds, Titicaca, nearly 15,000 feet above the level of the Pacific. On this road there are none of the bottomless gorges which Meiggs encountered, for the valleys are wider, and broad easy curves make unnecessary the V-switch arrangement. Meiggs' idea of a South American transcontinental line has been realized in Chile and Argentina. Buenos Aires on the Atlantic, and Valparaiso on the West Coast, have been connected by a railroad which rises only about two miles above sea level. The V-switch was used occasionally to obtain easier grades, but these were so few that finally the ordinary rail had to be given up and a toothed track, engaged by a cog-wheel on the locomotive, gives the necessary traction. Instead of making long, gradual sweeps, the line goes up in the form of a series of steps. There are short level sections over which the engine runs in the ordinary way, and in between these are the sharp inclines up which the train climbs by means of the cog-wheel. The winter snows give the greatest trouble on this line, but plows and dynamite keep the track clear of snow and boulders. Perhaps the most wonderful of the Andean railroads is the line from Arica on the West Coast, to La Paz, the capital of Bolivia. For the greater part of its 292 miles it lies at a height of over 12,000 feet. There are no tunnels and the grades are climbed by rack and pinion, the method used where gradients do not require the cog-wheel



ENTRANCE AND EXIT OF A HORSESHOE CURVE IN THE PERUVIAN ANDES

Some idea of the engineering difficulties met in such projects is obtained when one realizes that the temperature change in the mountains is sometimes as great as 110 degrees in a few hours. From 100° in the heat of the sun to below zero at night is not an uncommon drop. Many of the bridges are in one span. Twice daily these bridges are subjected to expansion and contraction strains, and have to lengthen and shorten about seven-eighths of an inch for each one hundred feet of their length.

NEARING THE SUMMIT OF MOUNT PILATUS

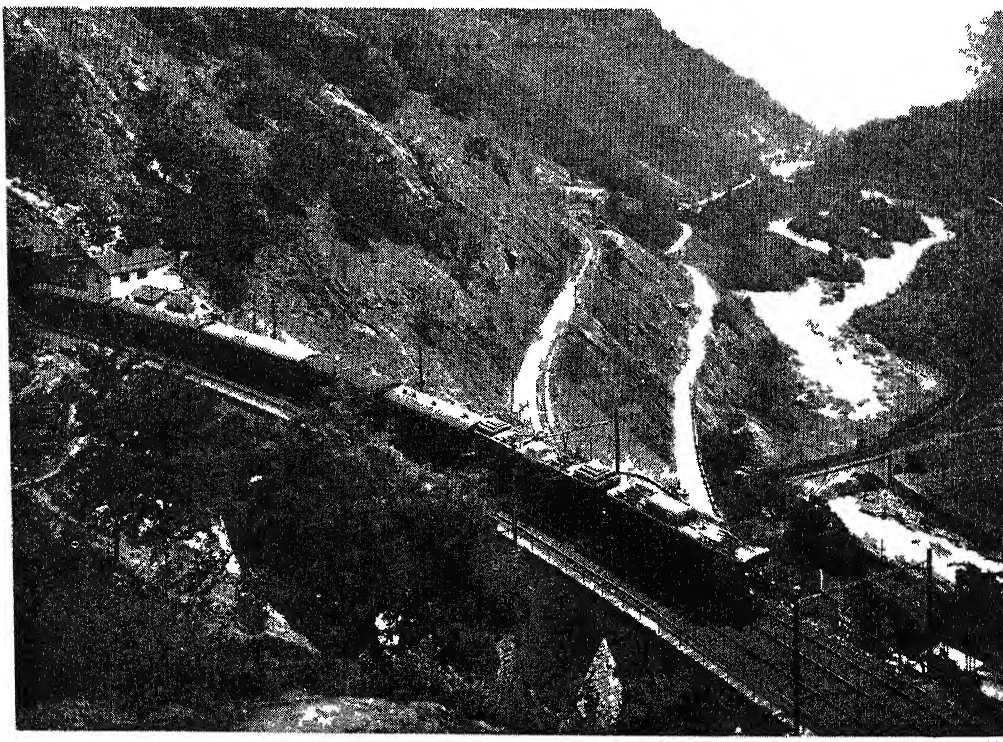


A RACK-AND-PINION RAILWAY FOR SIGHTSEERS IN SWITZERLAND

The photographs on these pages are by permission of Wehrli, The Peruvian Corporation, and the Canadian Pacific Railway.

This temperature effect is also felt by the rock and rubble along the line, and terrible landslides result, which have destroyed tracks, trestles and bridges One such landslide wiped out the Verrugas bridge on Meiggs' line

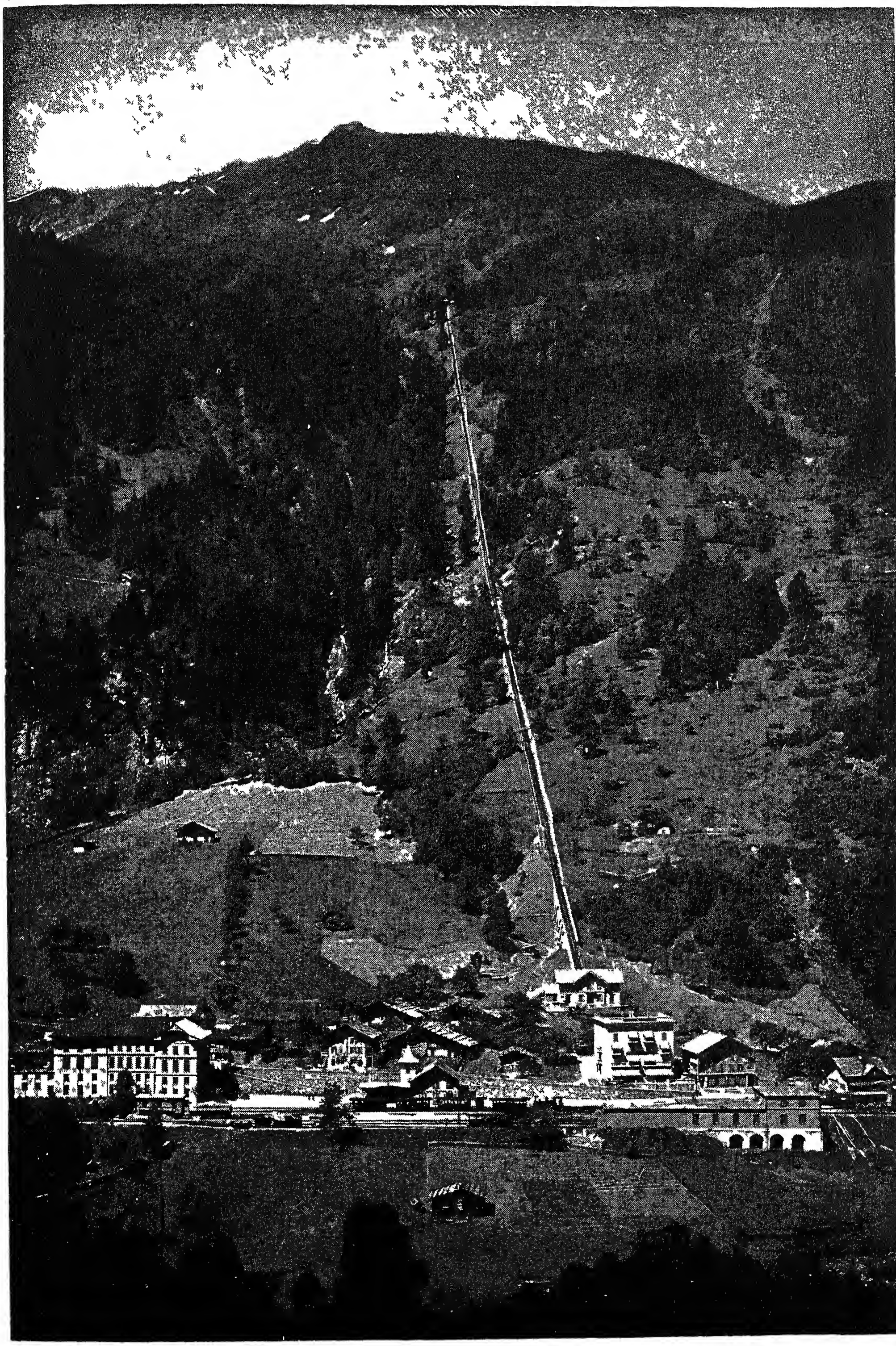
In North America there are older lines of mountain roadbed that offered seemingly insurmountable obstacles to the constructing engineers The state of Colorado has more than 120 mountains over 13,000 feet high The valleys between, if they may be called such, are deep, rocky canyons, whose walls often tower half a mile or more above the bed of the gorge The immense stores of mineral wealth in the Rocky Mountains have led to the settlement of towns of considerable size and population, like Leadville Mining camps are found 13,000 feet above sea level The demand of these towns and camps for a railroad was finally answered by capitalists who were willing to risk their fortunes in such a venture, and A A Robinson was one of the engineers chosen to construct the road The roadbed runs through the Royal Gorge, one of the most impressive and gigantic beauty spots of America Paralleling the river, Robinson laid his rails on a narrow ledge, until a 10-yard defile, with walls rising 3,000 feet direct from the water's edge, brought him to an abrupt halt For days the engineer wandered up and down the gorge seeking a way out of the difficulty Tunneling was too expensive to consider, a bridge pier would not withstand the thundering torrent, and finally he decided that the road must go through the narrow space between the gorge walls The solution of the problem was ingenious From a ledge not over two feet wide, hewn in the face of the rock, workmen threw girders across the stream and anchored the ends to the cliffs From these girders the track was suspended Five canyons are bridged before the railroad crosses the backbone of the North American continent



Black Star

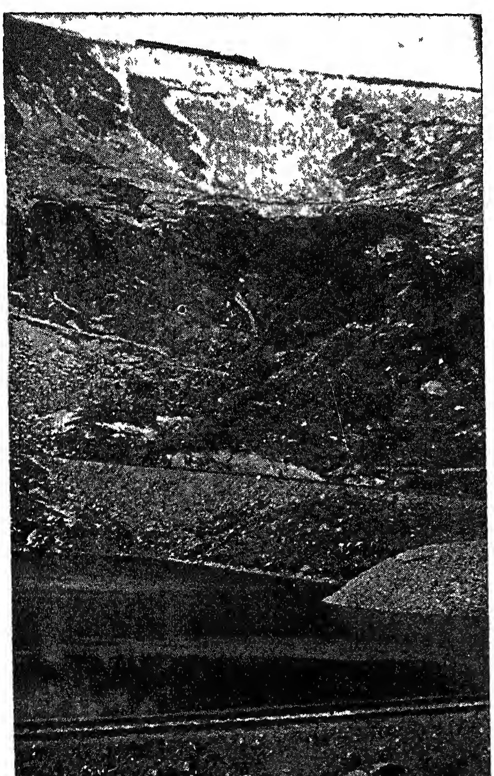
Switzerland's mountainous terrain confronts the railway engineer with immense problems Here the tracks of the St Gotthard Railroad wind across rivers and through tunnels on three different levels

THE CABLE LINE TO A SKATER'S PARADISE



THE RAILWAY FROM LAUTERBRUNNEN TO THE MOUNTAIN VILLAGE OF MURREN

THE STEEPEST RAILROAD IN THE WORLD
Lumber trolley road at El Portal, California.



CLIMBING THE ROCKIES
A train on the Continental Divide. Three levels of track are seen.

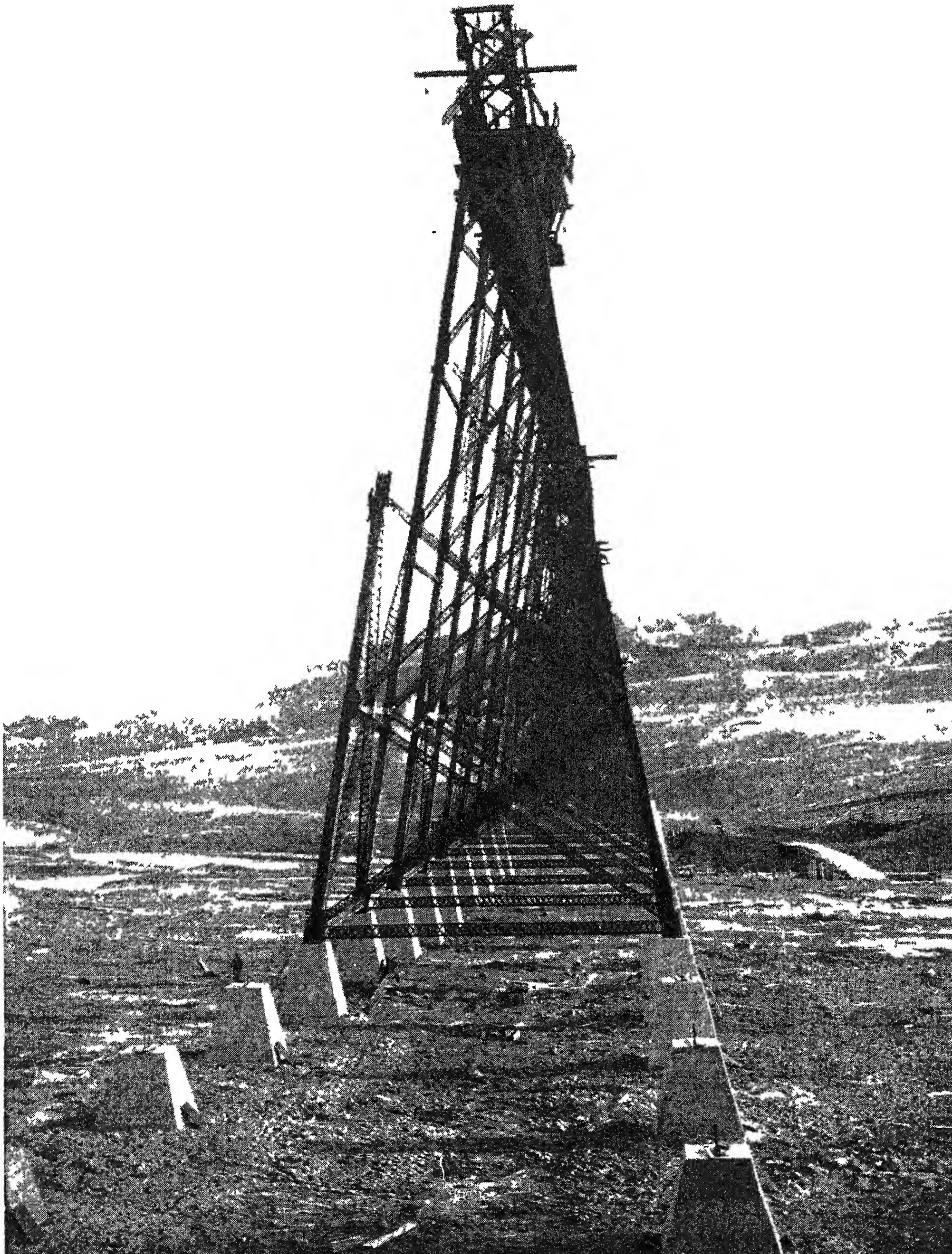
A full mile of really level track is hard to find. On one side of the mountains it is a continuous climb; on the other it is a long downhill coast with steam shut off. Two huge locomotives have all they can do to haul the trains up the grades, which in places rise a foot for every twenty-five of track.

When David H. M. Moffatt, a multimillionaire silver mine operator of Denver decided that his city should be connected with the Pacific Coast, his engineers knew that lack of money would be their least worry. Denver at this time was over a hundred miles from the line across the Rockies that Robinson had begun. Moffatt's plan was to strike out in a straight line for Salt Lake City, Utah, with his projected line.

No expense was spared to make the line as solid and strong as possible. Timber trestles were forbidden, and so many tunnels were bored that the "Silver King" was asked why he did not make one tunnel through the whole mountain range and have the job done with. Tunnels require time for drilling, and so the engineers went on with their track laying on easy grades and long loops until they crossed the Continental Divide through Rollins Pass, nearly 12,000 feet above sea level. Later a tunnel two and a half miles long was put through the mountains at a height of 10,000 feet, and while this handles the bulk of traffic both summer and winter, the older line was not abandoned, but is used for thousands of tourists who yearly view the magnificent panorama of snowfields, glaciers, and white-capped, majestic mountain peaks.

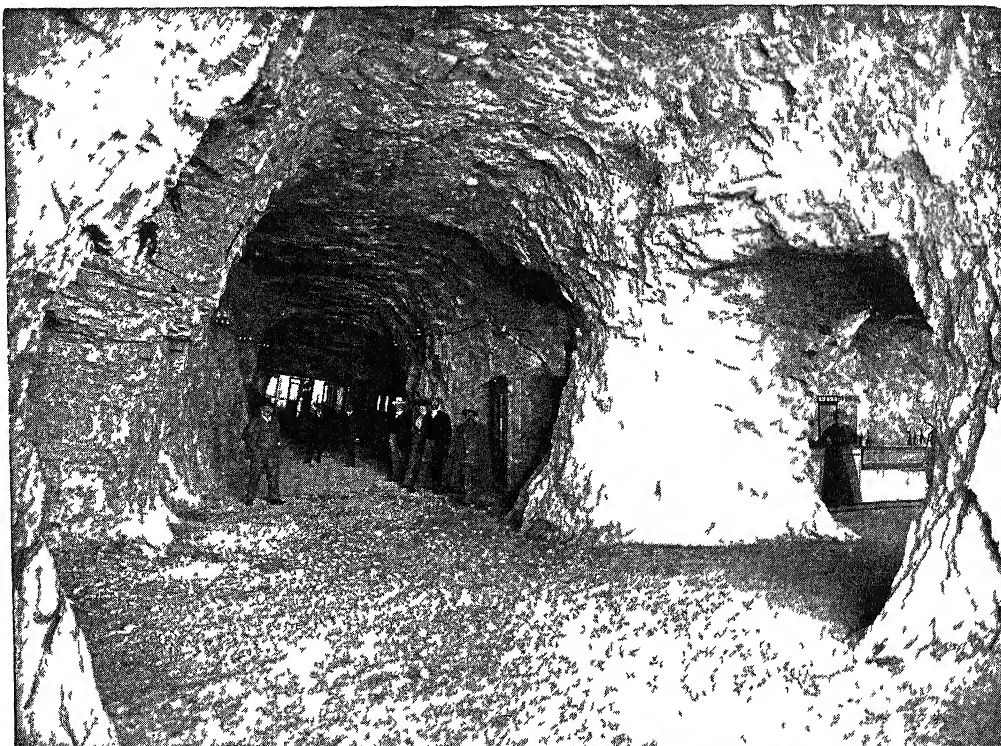
The highest mountain railway in the Rockies is that on Pikes Peak. It is nearly nine miles long, and rises over 14,000 feet above the sea. The country around can be seen for 100 miles on a clear day. The cog-wheel road is used here, as on Mount Washington in New Hampshire, and on Mount Pilatus in Switzerland. Short-line mountain railroads are common. None of them has the romance of engineering that is connected with the great lines over the Rockies and the Andes.

BRIDGING A PRAIRIE VALLEY & RIVER



This Battle River viaduct on the Canadian National Railways is one and a half miles long and 180 feet high, and is an interesting example of keeping up the level by bridging.

When one realizes that all of the steel for such a line as that built by Meiggs in the wildnesses of the Andean clouds was made and fashioned in the United States, and considers the difficulties of transportation that existed in 1870, he can better understand the heroic mold of the engineers who battled with nature at her worst and overcame the heartbreaking obstacles in their paths Were Meiggs to construct his road today he would find tunnels, lighted by electricity. The grade in places is as great as one to four. Special electric locomotives with brakes that apply automatically at a speed over $4\frac{1}{2}$ miles per hour are used for motive power. Even in event of the failure of the current these brakes will work, for on the down grades the electric motors may be made to work as generators which will furnish the electricity necessary to operate the brakes.



A STATION ON THE JUNGFRAU HEWN IN THE SOLID ROCK

hundreds of monster machines to make his task easier, and at the same time take out many of the romantic features of the work.

The Jungfrau, the most beautiful of the Swiss mountains, has an electric railroad running nearly to its summit. From the last station, hewn out of the solid heart of the mountain, an electric elevator takes the sight-seers to the summit. The road has been constructed with a view to keeping the natural beauty of the mountain free from the disfiguring hand of man, and therefore the road-bed lies in long

This railroad is purely for tourists, and during the winter snows the engineers and their staff are cut off from the world. Over a hundred tons of supplies are carried to them in the autumn to take them through the winter months. As long as the supply wires from the hydro-electric station hold together the snowbound community suffers no great inconvenience.

Electric power for all railroads is certain to come in the future, for aside from freedom from coal-dust there is the greater tractive effort possible, and the regeneration of power on long down grades. Par-

TWO INTERESTING AËRIAL RAILWAYS

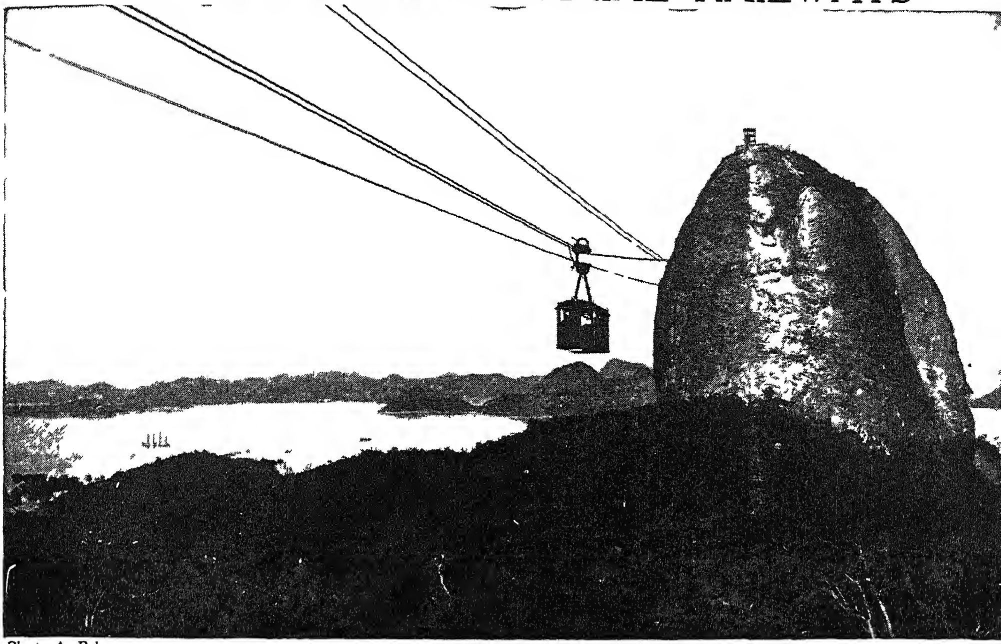


Photo A Ribeiro

Sugar Loaf aërial railway in Rio de Janeiro, 4500 feet in length The car weighs 3 tons and accommodates 20 passengers.

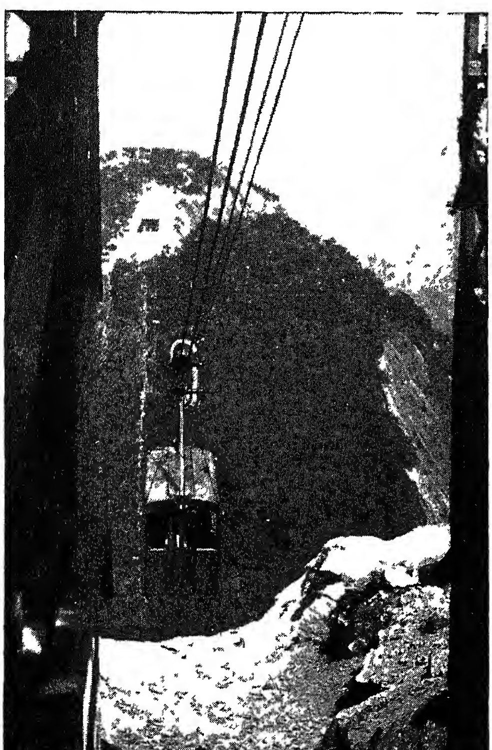


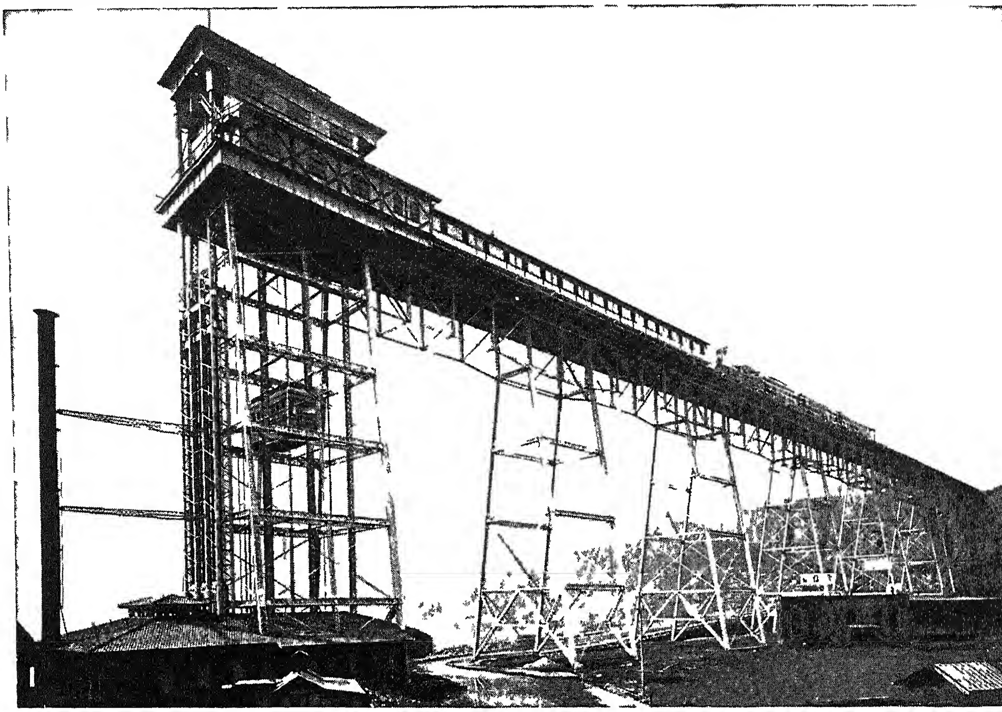
Photo Malta

Car approaching the summit of the Sugar Loaf, Urca station in the distance.

© Underwood & Underwood, N Y

Longest aërial railway in the world, at Baker, Col. This photo was taken at 7000 ft elevation.

OUTDOOR ELEVATORS THAT AVOID STEEP



Old time Weehawken (New Jersey) elevator   The viaduct was 800 feet long and 153 feet high

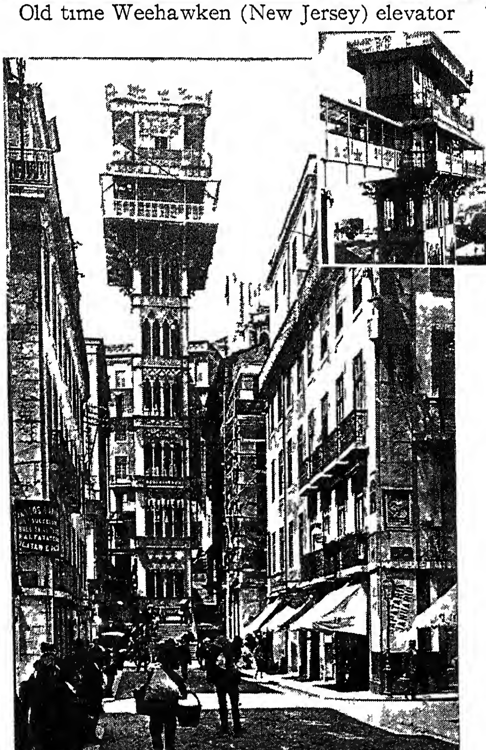
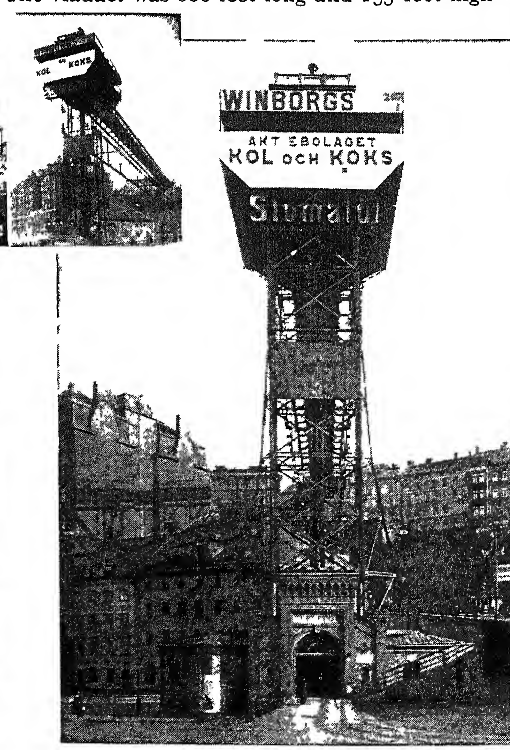


Photo Benoliel

Santa Justa elevator in the shopping district, Lisbon (Portugal)



The ' Katrinahissen ', street elevator in Stockholm (Sweden)

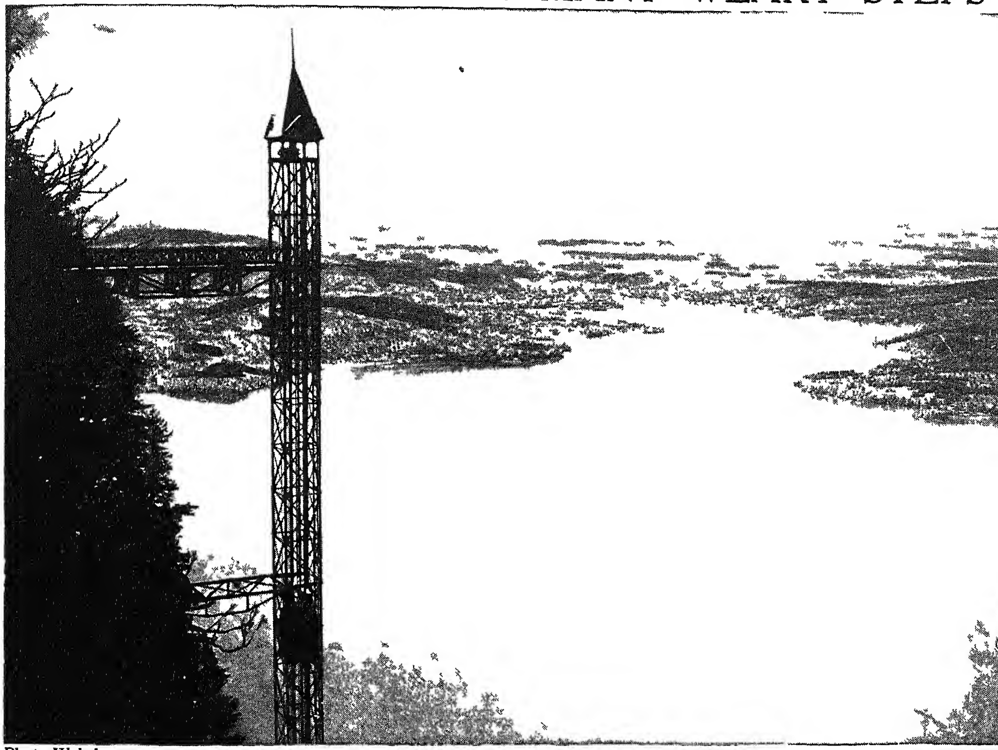
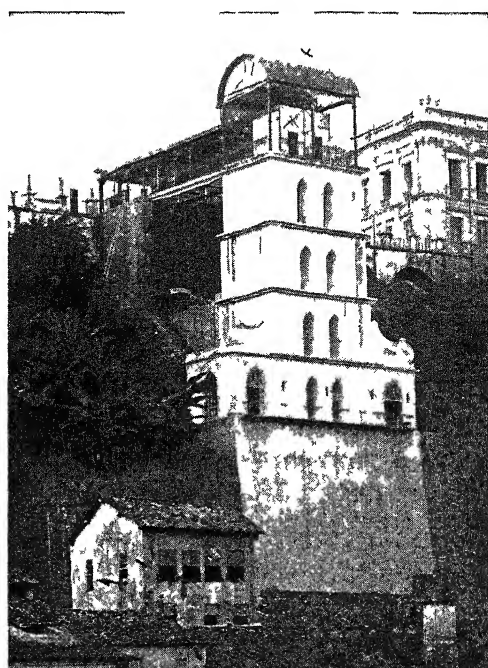


Photo Wehrli

Burgenstock elevator, looking towards Lucerne (Switzerland)

Photo Benoliel

Municipal elevator to the public library, Lisbon (Portugal)

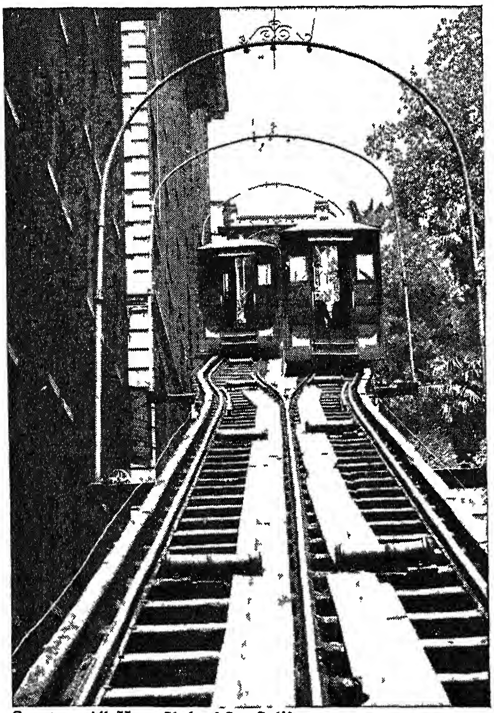


Courtesy Pan American Union

Elevator at Bahia (Brazil), connecting lower and upper city

ticularly in mountainous districts will the electric locomotive find place. Hydro-electric power stations will supply the electricity, and the regeneration of power on down grades may reach as high as 15 per cent, the effort of the locomotive in this regeneration being used as a braking action to check the rapidity of descent.

Under conditions where, no matter what the grades or the ingenuity employed, surface railroads are impossible or impracticable, aërial lines have sometimes



Courtesy All-Year Club of So. Calif.

ANGELS FLIGHT, IN LOS ANGELES

This cable tramway, 315 feet long, climbs a 33 per cent grade. Each car can carry 32 passengers. As one car ascends, the other descends. Note the center track which both cars use in common, except at the passing point.

been constructed. The longest and highest one in the world is at the Baker Mine, Baker, Colorado. It is over a mile long, and our picture was taken at an elevation of 7000 feet. The Pão de Assucar (Sugar Loaf) aërial railway, in Rio de Janeiro, connects the city with the imposing stone cap which overhangs the harbor. It is in two sections; the first, which starts at sea level, runs to the top of the Urca (680 feet), a distance of nearly 2000 feet. Here the passengers change cars and proceed over the second section which spans the deep valley between the Urca and the Sugar Loaf (1200 feet), over 2500 feet away. The cost of installation was about $275,000. The view from the summit is magnificent, and the line is much patronized, over 500,000 passengers having been carried without an accident in all the years it has been running. The cars accommodate 20 passengers and weigh three tons. They are suspended on two steel cables, which act as tracks, and are deeply anchored at each end. The two power-houses are on the Urca.

In cities built on hills, especially abroad, outdoor elevators for foot passengers are often used to save the stiff climb. In this country there used to be such an one for reaching the top of the Palisades. In the early nineties, the high tableland in New Jersey, opposite New York City and between the Hudson River and the Hackensack, was, of course, not developed for pleasure and residence as it is today. For one thing, it was difficult of access; steeply graded wagon roads or laborious stairways up the cliff were the only means of approach until the Hudson County Railroad increased these facilities by means of huge hydraulic elevators at Weehawken. These rose just from the water's edge, where the ferry boats from 42d Street and Jay Street discharged their passengers, and where also the West Shore started north and west to Albany and Buffalo. From the elevators a viaduct 153 feet above the water ran about 800 feet back to the hill. The elevator tower was made for three cars, each of which ran independently of the other and could carry 135 passengers, or 6000 each way in every hour. As in the Lisbon elevators, shown in our illustrations, the doors were almost as wide as the cars, and the conductor with a simple device, similar to that used in the subways and elevated trains, opened and closed both doors at once. On one side the passengers were discharged, while others entered from the opposite, so that in rush times the cars emptied and filled almost at the same moment.

THE TRUTH ABOUT TOBACCO

Things Taken into the Body That It Does Not Need, but Tries, Sometimes Unsuccessfully, to Endure

THE UNDOUBTED EVILS OF DRUGS

ONCE we have begun to discuss drugs and their effects, we discover that the subject is easier begun than left, for it involves a good deal more than the doctor's prescription or the morphinomaniac's needle. Nor must familiarity deceive us as to the character of drugs which, perhaps, we had never thought of as such, say, for instance, the alkaloid caffeine, found in coffee and tea, or the theobromine found in cocoa. Further, we are not to be deceived by such facts as that the drug in question produces no ill-effects, or none that we can detect; or that it is habitually taken by healthy and sensible people — such as ourselves; or that the drug is not swallowed, or not chiefly swallowed, but is merely inhaled or absorbed from the nose, like the nicotine and other drugs contained in tobacco. We need only remind ourselves that the most effective way of administering chloroform is by the nose and lungs. Yet the fact is that very few people, outside the medical ranks, are prepared to talk or think honestly on this subject. Like nearly all of us, in one direction or another, they will do the thing, but they dislike its name. The smoker has a drug-habit, and so has anyone who habitually takes coffee or tea. This does not mean that tobacco, coffee and tea are either better or worse than they were before, but it simply means that we have named things properly — which is the first step to understanding them. And now we can proceed to examine the action, the uses, if such there be, the abuses, if such there may be, of these various drugs, and the appropriate treatment of any ill consequences.

We are to be fair-minded, even when we have called a spade a spade and a drug a drug, no less than — indeed, more than — when we preferred to use the name "drug" only for what our neighbor uses and we refuse. The simple truth is that there are drugs and drugs, and there are cases where the exact definition is almost impossible. But we need not be tied down to any definition, more especially as the old ideas about foods are breaking down, and we learn that substances may be useful in the diet, or essential, though they do not "form tissue or produce energy." When we supposed that nothing was a food that did not do one or both of those things, we could confidently call everything else a drug, but we see that this simple mode of judgment is *too simple;* for a normal diet, as we shall learn in due course, contains numerous chemical substances which neither form tissue nor produce energy, but which we should die without. Common salt, for example, a necessary ingredient of our diet, does neither; it is a chemical compound and is essential for the proper working of the body.

The same is true of several other substances. Without them we die, or are very ill. But the case is quite different with the drugs which are now to be discussed. Common salt is found in normal, natural articles of diet, such as wheat and flesh; and if any advocate of some food theory questions that one or both of these are normal, we need only refer to the one food-substance that owes its existence to the purpose of being consumed, which is milk. Milk contains common salt. So do the tissues of the body.

Let it be shown, now, of any substance that it is found in normal milk and in the normal body, and it is beyond criticism. Let it be shown of any substance that it is *not* found in milk (the complete and perfect food for, at any rate, the most important stages of development), nor in the normal body, except perhaps as a waste product, and it is, on those two grounds, open to criticism, and demands it.

Let the reader duly observe, then, that we have substituted a genuine, natural, scientific criterion for such absurd and thoughtless ones as are usually allowed to suffice. The question is not whether, say, caffeine or nicotine does no harm, or does one good, or is used by everybody; all these assertions may be true, but the substance is no less outside the physiological pale if we find that it does not occur in the only food made to be a food; and that the normal body does not contain it. We have only to think of the constituents of milk, its albumin, fat, sugar, salts, water, and to compare them with the composition of the body, which consists of just the same things, in order to see how real and deep is the line here drawn, the line which we call the physiological pale, and outside of which are, for instance, the alkaloids found in such plants as provide us with coffee, tea, cocoa and tobacco — to say nothing as yet of that product of the decomposition of sugar by the yeast-fungus, alcohol.

The difficulty of excluding the idea of bias when discussing tobacco

Everyone who has had an elementary course in chemistry knows at once that nicotine can only be classed with atropine, found in belladonna; that caffeine can only be classed with morphine, and alcohol with ether, which is a chemical modification of it. These things may be good, bad or indifferent, which is what we have to determine, but at least let us know where we are when we discuss them. We are among substances which do not exist in normal food, and are not constituents of normal protoplasm. Even in the plants which produce them, they are not parts of the living substance, but are products of excretion.

We may begin with tobacco, which is a subject of greatly increased importance during recent years, owing to its considerable use among women as well as men. The man of science has the utmost difficulty in persuading people that he writes impartially on this or any subject which comes so close to the likes and dislikes of his readers. Those who like what he says will applaud, and those who dislike it will dismiss him as biased.

Smoking the least harmful form in which tobacco is used

Tobacco may be either smoked or chewed, and the action of its contents is essentially the same in the two cases, only that chewing is much more likely to be practised to obvious excess, owing to the action of combustion upon tobacco when it is smoked. But we must be quite clear that, notwithstanding popular statements often made, the essential constituents of tobacco are absorbed by the smoker as well as by the chewer. This we shall see when we have first defined the composition of tobacco. To do so completely would require a treatise, for the chemistry of the tobacco leaf is extremely complicated, and it varies in considerable degree with different kinds of tobacco, and according to the particular microbes which have been at work in the process of curing it. For our purpose it suffices that tobacco in general contains a proportion of nicotine, and a number of other substances, less potent, but far from inert. Some of these substances, if isolated from the leaf, and used even in quite small quantities, are found to be surprisingly powerful. But the quantity of nicotine and the other active principles in ordinary tobacco, is, of course, very small, or smoking, to say nothing of actual chewing, would be quite out of the question.

Nicotine, weight for weight, slightly more poisonous than prussic acid

One-third of a grain of nicotine has killed a man; and if we compare this drug with prussic acid, weight for weight, nicotine is slightly more poisonous; indeed, chemistry knows few poisons more powerful.

It follows, obviously, that the quantity of the drug which enters the blood when tobacco is smoked or chewed must be exceedingly small.

The question arises, however, whether there is any nicotine in tobacco smoke; and at one time it looked as if there could not be, for nicotine is combustible, and during the process of smoking tobacco much of the nicotine is certainly burned up and destroyed, being reduced to mere carbonic acid and water and innocent nitrogen. Certainly all the nicotine that still remains in the portion of tobacco that is being burned at any given moment is consumed. Probably, also, the heat of the combustion is sufficient to oxidize and destroy all, or nearly all, of the nicotine in the tobacco that is just about to be burned, and is so near to the site of combustion as to be very hot; hence the clause "that still remains," when we spoke of the tobacco actually burning, for in that probably very little nicotine is present to be burned.

Does the volatility of nicotine reduce to insignificance the amount absorbed?

But the great characteristic of nicotine is its volatility. When it is warmed it becomes a vapor or gas — a most exceptional characteristic for an alkaloid, and one which sharply distinguishes nicotine from nearly all familiar alkaloids, such as morphine and strychnine. Hence, as one draws in a mouthful of smoke, one draws in with it a certain amount of nicotine in gaseous form, derived from some part of the tobacco between the lips and the part undergoing combustion. No doubt the proportion is tiny, but the substance is potent.

If the smoke puffed out by the smoker be examined for nicotine and other constituents, we find very scant traces of any of its volatile constituents, for these have been to a great extent absorbed, and it is this absorption that matters everything, and must be carefully defined. It has often been asserted that smoking really owes its attraction to the sight of the smoke, and that blind men do not smoke. Inquiry among the blind contradicts this.

The interest of the smoker dependent on the absorption of the poison

It is true that mere taste is an element, though a subordinate one, in smoking, and that seeing people can scarcely taste in the dark. But when one has become accustomed to the dark, as the blind man does, the sense of taste learns to do without the accessory stimulation of the nerves of sight. The blind man eating his dinner enjoys it as we do, and very much more than we should if we had to eat it in the dark, as he does. Hence the blind man is not deprived of the taste element in smoking. But even if he were, smoking is still welcome to him, as it is to those whose sense of smell has been atrophied from one cause or another. There is no need whatever to try to invent novel and fantastic reasons for smoking; the real reason is beyond dispute, and is simply the effect produced by the absorption into the blood of nicotine and certain other constituents of tobacco smoke.

If there were no such absorption, smoking would be of no interest to the hygienist, except for its possible effect upon the mouth, tongue, and lips; and, indeed, it would be of no interest to the smoker. Just as we live not by what we eat, but by what we assimilate, so the effects of nicotine depend not upon its entrance into the mouth, but upon the amount of it that actually circulates in the blood and reaches the nervous system. The amount entering the blood varies in different people, according to the mode of smoking, and so forth; and the proportion existing in the blood at any given moment probably varies according to the idiosyncrasy of the smoker, and the rate at which his tissues and blood burn up the poison — just as is doubtless the case with morphine and alcohol.

The amount absorbed measured by the absorbing surface exposed

But, other things being equal, the amount of nicotine entering the blood must depend upon the area of absorbing surface which is exposed to the smoke. Necessarily very much less nicotine is absorbed

from the mouth only, than when the smoke is exhaled through the nose, and past its large and delicate mucous membrane, which is richly supplied with blood-vessels, and has considerable powers of absorption, as the snuff-taker demonstrates Further, the surface of the nose has valuable functions of its own to discharge, and is very liable to injury and degeneration of various kinds On these grounds the smoker may be advised to avoid the habit of exhaling the smoke through the nostrils — though the satisfaction of doing so, and offering a larger absorbent surface to the smoke, is quite intelligible

But if that practice is somewhat to be frowned upon, far more serious words are required when we come to deal with the second method by which the smoker increases his area of absorption and so obtains a more intense action of his drug This is the practice of inhaling the smoke The reader has only to consider his elementary anatomy in order to realize that, when the smoke is exhaled through the nose, it need not have been really inhaled at all, but merely allowed to pass into the nose from the back of the mouth, behind the soft palate, which the smoker drops for the purpose — instead of keeping it raised and shutting off the nose, as he does when he swallows But the inhalation of the smoke is a different matter altogether It means the passage of the smoke into the windpipe and bronchi, and the exposure of the delicate lining of these air-vessels to it, and thus the absorption of much more nicotine than the mouth and nose can possibly take up That, of course, is the reason why the smoker inhales.

A simple test of the amount of deleterious matter absorbed from tobacco

A simple index of the difference between ordinary smoking and inhalation may be furnished by passing the smoke from the lips through a handkerchief in the two cases respectively, and comparing the stains, when the smoker will find that a much slighter stain is produced by the smoke that has been inhaled, showing how much of its contents, whatever they may be, has been left in the lungs

This convincing test is, however, only an index of absorption of nicotine The brown mess on the handkerchief is not nicotine in either case, any more than the oily mess that accumulates in a pipe and is commonly called nicotine by smokers Since much less than one drop of nicotine will kill a man, it is plain that the visible brown material in the pipe, or on the handkerchief in this test, can only contain an extremely minute proportion of nicotine, if any Nevertheless, the handkerchief test remains, and there is every reason to suppose that the smoker is decidedly better without the brown material which the handkerchief intercepts when the smoke has not been inhaled, even though nicotine be not among its many constituents

Inhalation the special and serious danger of cigarette smoking

Few smokers can ever learn to inhale the smoke of a cigar or a pipe — for a reason which we shall have to study soon Therefore the inhaler smokes cigarettes, and the possibility of inhaling their smoke is thus the special danger of cigarettes The habit is one of which few people can break themselves, and it is highly desirable that the young smoker should be warned against it As long as one has never inhaled smoking is just as enjoyable and far safer without it Unfortunately, the young person rarely lacks a supply of eager tutors glad to teach him or her an undesirable habit, in this as in any number of other directions This is one of the facts of human nature which are so common as to seem normal, and yet are evidently morbid, but there the fact is, and the best we can do here is simply to warn any young reader in especial, that if he or she is encouraged to try the inhalation of cigarette smoke it is well to look to the end thereof before making the experiment

Fortunately, many people cannot inhale even mild smoke, because of the resentment exhibited by the larynx For let us remember that every atom of gas, dust smoke or anything else which enters the lungs must do so by the only route, which is through the tiny aperture between the two vocal cords in the larynx or voice-box

The lining of the vocal cords is intensely sensitive, as it should be, for they are not only the reeds of the human pipe, but also the responsible doorkeepers of the lungs. Hence the first attempts at inhalation naturally excite coughing, and even the most seasoned inhaler of cigarette smoke will cough if he accidentally inhales the smoke of a pipe.

The great tragedy of spoiled voices and of poisoned tissues

In time, however, if the novice persists, he will find that he can inhale without coughing or serious discomfort, and lastly with pleasure — the converse of the pain which he feels when he is deprived of what he has induced himself to need. But this insensibility of the vocal cords and lining membrane of the larynx is not purchased for nothing. It means that the lining has become thicker and coarser, just as the skin of the hand or the heel responds to irritation, friction or pressure; and if the lining of the vocal cords becomes thick and coarse (as even frequent and prolonged use in speech and singing need never make it), the voice becomes husky and loses its beauty and reliability.

In many cases this is a real tragedy. It is a pity whenever it occurs, but especially so when it occurs in those who have beautiful voices, and who often depend upon them for a livelihood. Doctors and, above all, doctors who specialize in the throat and larynx, know how constantly young singers lose their voices and spoil their careers because of this vice of the inhalation of cigarette smoke. It *is* a vice; for its consequences are vicious, and the essence of it is maltreatment of one of the most delicate and irreplaceable parts of the body — the organ of the "living voice".

Lotions, gargles, medicines, change of air, may all be tried, but they will all certainly fail, and the trouble, even if relieved by vocal rest, will certainly recur, unless and until the cause is removed.

Nothing easier, anyone may say who has no idea what these drug habits mean. But no one will say so who has fairly faced the facts, for nicotine is a characteristic representative of what are called the neurotic poisons, because of its action on the nervous tissues; and we shall soon see that these poisons have an insidious method of establishing themselves, so that they can scarcely be distinguished from our natural needs, like air and food and water.

The absolute certainty of the poisonous character of the nicotine drug

The fact that tobacco is a poison is no more disputed by anyone now than the like fact regarding alcohol. It is curious that the people who argue that alcohol cannot be a poison because so many people took it without apparent injury do not apply the argument to nicotine, which would show its absurdity. Nicotine is no less a poison because the adult is usually capable of acquiring what appears to be a complete immunity to its action. Let him remember the bad quarters of an hour which his acquirement of immunity cost him. Let him remember also that the nervous paralysis produced by tobacco, when pushed, is extreme. It may lead to death, and would do so in any man or animal not protected by habit. Short of that, this action of tobacco used to be deliberately employed by surgeons, in the days before anæsthetics, in order, for instance, so to weaken the nervous system that the muscles around a dislocation might be relaxed, and the surgeon could then reduce it.

The objection to the description of nicotine as a poison is naturally raised by the habitual smoker — the case being the same with alcohol, opium, cocaine and all the other neurotic poisons which induce habits. The habitual smoker, as, for instance, the patient with a smoker's throat, when told to stop smoking, or at least to stop inhaling, replies that the tobacco, so far from being a poison, keeps him well. He tries to drop it for one day, and finds himself so nervous and shaky and miserable — in fact, so *poisoned* — that he is almost bound to start again in order to obtain relief. Thus smokers argue that smoking "steadies their nerves", increases their sense of well-being, and favors digestion; that the after-breakfast smoke is a useful aperient, and so forth.

The smoker's pleasure the satisfaction of an artificially acquired craving

But the fact is that the satisfaction which the regular smoker obtains is precisely the same in essence as that obtained from his alcohol by the drinker, or from his morphia by the morphinomaniac. This is the satisfaction of an artificially acquired — if indeed we must not say a morbid — craving. The drug is in itself a poison, probably to all forms of life, just as alcohol and prussic acid are, though both of these are produced by living plants more or less directly. If close enough chemical inquiry were made, we should probably find that, as is known in the case of morphine, and as is doubtless true in the case of alcohol, the poison produces from itself secondary poisons which require a further dose of the original poison as an antidote to them. Thus a vicious circle is initiated, the details of which have been apparently fully worked out in the case of morphine, and it notoriously consorts with the general experience in the case of these various narcotics.

The special reasons why women, especially expectant mothers, should not smoke

As regards the use of tobacco by women, there is no reason to suppose that there is any essential difference between the two sexes in this respect, with one exception. That exception is the expectant mother, who, if she smokes, must undoubtedly be exposing the young tissues and the developing nervous system of her child to a deleterious influence. No exact observations exist on this subject, unfortunately; nor is anything known as to the possible excretion of any constituents of tobacco smoke in the milk of the nursing mother.

Interesting experiments by the chief executive of the Boy Scouts of America

Though the great majority of smokers *appear* to acquire complete immunity to their drug, and though nearly all soon reach a degree of dosage which they are not tempted to exceed, or which, at any rate, they can and do refrain from exceeding, the matter cannot be dismissed so lightly.

Some interesting experiments as to the extent to which the use of tobacco is injurious, are recorded in Fisher and Berry's "The Physical Effects of Smoking". A long series of tests were made with a number of healthy, vigorous, young men between 21 and 25 years of age, in good condition, none of them hard smokers and some of them non-smokers, over a period of several days and under like favorable conditions. At first one cigar only was smoked, yet in most instances a measurable increase in the heart rate, already normally higher in the smokers than in the non-smokers, and an increase in blood pressure, resulted. With cigarettes, it seemed only a question of comparative amount of tobacco — unless the smoke were inhaled, in which case the effect of a single cigarette equaled that of one cigar.

The time taken by the heart to return to normal was significant, and a further experiment was made to determine how smoking *and* exercise would affect this. The men made 20 jumps over a bar 18 inches high, at the rate of 80 to a minute, timed by a metronome. In 72 out of 74 cases without smoking, the heart rate returned to normal in less than 15 minutes, the average being 5 minutes. In 74 out of 118 cases after smoking two cigars, the heart had not returned to normal at the fifteenth minute. The average rate was then 11.2 beats faster than the average normal.

The effect of smoking on neuro-muscular precision

To measure the effect of smoking on neuro-muscular precision, two sets of experiments were made, one on the smaller and finer muscles and one on the large muscle coördinations. The former consisted in drawing a zigzag line between, and without touching, two parallel lines $\frac{3}{16}$ of an inch apart; the latter in making five straight-armed thrusts with a fencing foil at a target 15 inches in diameter placed shoulder high.

All smokers showed a lesser loss than the non-smokers in physical precision immediately after smoking, and a greater lack of neuro-muscular control after exercise.

The effect of smoking or non-smoking on baseball players' throwing

To apply this experiment to a popular sport, twelve baseball players, smokers and non-smokers, were chosen, and official league balls thrown at a target 5 feet square, with a bull's eye 12 inches in diameter, shoulder high, at a distance of 60 feet. Thirty throws were allowed, ten before smoking, ten after smoking one cigar, and ten after smoking two. The average loss in accuracy after smoking one cigar for both smokers and non-smokers was 12 per cent; after two cigars, 14½ per cent. In tests during which there was no smoking the men improved in accuracy.

The significance of these results may be judged from the fact that an increased heart rate of only 5 beats per minute means that a man's heart does 2074 kilogrammeters (approximately 15,000 foot pounds) more work per day. In fifty years this means 272,471,000 foot pounds of unnecessary work. This may mean, other things being equal, five years less life, less margin of safety, less recuperative power, more danger in the crises of disease or accident. And as the blood pressure is also raised, even these figures do not represent the whole truth, for the unnecessary work of the heart is even greater.

Prompt return of heart to normal after exercise indication of physical fitness

More significant than the actual heart rate is the reduced nervous control of the heart, even with such small amounts of tobacco. Failure to return to normal, after exercise, within a reasonable time is sufficient reason for denying a place on a team to a candidate. A strong, slow. regularly-beating heart which returns quickly to normal after moderate exercise is taken by athletic trainers as one of the surest indications of physical fitness. Here is an evil influence which quickly and definitely upsets this condition. Trainers have long refused to permit men in training to smoke. They knew clinically that it was bad. Evidently they are eminently justified in their position.

Action of tobacco on the throat irritant, on the heart and eye toxic

There are, of course, definite disorders due to smoking, well known to medical science, quite apart from such questions as to whether, for instance, the effect of prolonged smoking upon the arteries is to induce arteriosclerosis, an increasing malady among our middle-aged business men. In such directions as that we still need much more knowledge, for whatever action exists must certainly be slight; but as regards the heart and the eye the possible effects of over-smoking (whatever quantity that may exactly mean for the individual in question) are clear and characteristic, like the effect upon the throat. This latter, however, is more a question of local irritation by means of heat and irritant particles, while the action of tobacco upon the heart and eye is purely toxic.

Nicotine, as we have said, is a typical neurotic, or nervous, poison. The slight tremor of the extended fingers of the excessive smoker is an indication of this action. Closely allied to it is the symptom known as "tobacco-heart", with its irregular, hasty, unstable pulse, and attendant consequences. Here, no doubt, the action of the nicotine is not upon the muscle fibers of the heart, any more than it is upon the muscular tissue of the arm, when it produces finger-tremor; it is almost certainly upon the nerve-cells in the nerve-ganglia of the heart, which initiate its beat.

The special ailments of tobacco-heart and tobacco-blindness

"Tobacco-heart" is a very common result of inhalation of cigarette smoke, and it also occurs not infrequently in those who chew tobacco. The problem for the doctor and for the patient in such cases is to remove the cause; but, as we have seen, that involves breaking a vicious circle, and mere injunctions and exhortations may not suffice. Even more serious is "tobacco-blindness", a very characteristic condition, in which the sensitiveness to light of certain parts of the retina is lost.

This terrifying condition is most frequently met with in those who chew, and especially in workmen who have learned the habit of chewing early in the morning before breakfast, for then the absorption of the constituents of the tobacco is made easier and quicker. The symptoms in the throat and larynx are often very obstinate, even when the cause is removed, for there the cause is acting in a different way, and is liable to produce structural changes in the parts affected.

The possibilities of cure for those who give up the use of the drug

But "tobacco-heart" and "tobacco-blindness" are recovered from with great rapidity and completeness, almost invariably, if the tobacco be stopped. The reason is that here the disorder is not organic, but functional — that is to say, the poison has not damaged any structure, so far as we can observe, but merely interferes with the function of the nervous structures, while it is present. If, then, the poison *and its secondary products* can be got rid of, the normal functions, whether of the nervous structures of the heart or of the eye, will be restored, and that is what we usually find. It is a fortunate fact, and notably to be contrasted with the action of certain other neurotic drugs, like alcohol, which is also a local irritant wherever it is carried, and is thus liable to leave permanent changes behind it in some degree. But the problem of leaving off the tobacco remains; and only those who have not experienced this craving and the distress of refusing to gratify it will grudge space to its consideration.

The need for real consideration for those who seek to give up smoking

As in the case of other drug habits, the smoker who is trying to break or reduce his habit requires real consideration. His habit may be in some cases a vice, and one which he deliberately began, but he is now in the grip of a vicious chemical circle, the first poison producing secondary poisons, which require a further dose of the first to neutralize them, and so on. It is found that tincture of *nux vomica*, prescribed by a doctor — for it contains the poison strychnine — may sometimes help the patient. The sucking of strong peppermints is widely reported to be useful in allaying the crave of the deprived smoker, and this is what we might expect from the known action of oil of peppermint upon the nervous system.

Most men can help themselves to keep down their smoking by making rules as to when they begin, or how much they will allow themselves, every day. "Lead us not into temptation" remains always psychologically true, and it is a good rule not to carry extra tobacco about with one. In the breaking of this, as of other habits, it is probably easier to be thorough from the first, and to remember that a single backsliding will neutralize a great deal of previous courage and self-control This rule does not apply to opium and morphine, however.

Serious dangers to which smokers are specially exposed

Smokers are notoriously more liable to cancer of the lower lip, mouth and tongue than are non-smokers, this being in accordance with the general rule that chronic local irritation of any kind is liable to set up the cancerous process. The lower lip is attacked especially in those who smoke a very hot-stemmed pipe, such as a short clay, and these cases are probably rarer nowadays than they were. The tongue is very frequently affected, however, not nearly enough having yet been done to warn the public as to the exciting causes of cancer, and the way in which to avoid them. The study of cancer brings more and more facts to light. But it can never be too soon to warn the smoker, above all as he approaches the later forties and onwards — though many cases occur before then — that he should take instant warning from the development of persistently irritated or whitened or thickened patches on any part of his tongue, whether the "smoker's patch" on the back of the tongue, or those which often occur near the point where the smoke from the pipe is habitually directed into the mouth.

CLIMATES OF THE PAST

by

CHARLES MERRICK NEVIN, Ph.D.

Assistant Professor of Geology, Cornell University

THE role of climate today indicates its great importance throughout the millions of years of past time, and suggests how vitally it will influence many activities on the earth of the future. Every living species of animal and plant develops best under certain limited conditions of sunshine, humidity and temperature. In the tropics, the temperature of the surface water of the ocean is about 30 degrees centigrade; and if the temperature rose to 60 degrees centigrade, for any considerable length of time, animal life would perish. On the other hand, most plants and animals cannot long withstand temperatures below the freezing point of water.

The fossil record, with its evidence of the persistence and development of life for something like a billion years, therefore conclusively demonstrates a remarkable uniformity of climate since the beginning of decipherable geologic history. In this record there is no evidence of extremely high temperatures such as exist on the sun, nor of the low temperatures which characterize the immensity of space.

This relative uniformity of climate for hundreds of millions of years is truly astonishing. For instance, we must infer that, since life first appeared on the earth, the sun has been pouring out radiant energy at about the same rate as today. Or, putting this in a slightly different way, we must infer that the sun has been losing weight at the rate of four million tons a second—something like 650 times the rate at which water pours over Niagara Falls—for at least a billion years. Thus, for every ton which existed as matter in the sun originally, only a few hundredweight remain today; the rest of the ton has been transformed into radiation and spilled through space as light and heat.

Simple shrinkage of the sun by contraction, with a resulting increase of heat, could not possibly account for all of the radiant energy required to preserve a relative uniformity of climate through the ages. Radiation, and the climate resulting, must be brought about by actual destruction of matter itself—a disappearance of atoms, and a transfer of their weight into radiant energy. When we speak of coal as "bottled sunlight" that was stored for use in the vegetation, to be converted into heat energy by man millions of years later, we therefore do not go far astray; in reality, it is re-bottled energy, as the first storing occurred when it was penned up in the electrons and protons in the sun.

But, if the sun is actually destroying itself continually, will not a time come when the radiant energy falling upon the earth will be lessened to such a degree that this uniformity of climate can no longer be maintained? The question is only natural and perhaps the best way to answer it is to quote from Anatole France's immortal description of The Last Man:

"There was a time," he says, "when our planet was not suitable for mankind; it was too hot and moist—a time will come when it will cease to be suitable; it will be too cold and dry.

"When the sun goes out—a catastrophe that is bound to be—mankind will have long ago disappeared. The last inhabitants of the earth will be as destitute and ignorant, as feeble and dull-witted, as the first. They will huddle wretchedly in caves alongside the glaciers that will have buried peoples and races, and obliterated the towns and cities.

"Women, children, old men—crowded pell-mell in their noisome caves, will peep through fissures in the rock and watch a sombre sun mount the sky above their heads; dull yellow gleams will flit across his disk, like the flames playing about a dying brand, while a dazzling snow of stars will shine on all day long in the black heavens.

"One day, the last survivor, callous alike to hate and love, will exhale to the unfriendly sky the last human breath. And the globe will go rolling on, bearing with it through the silent fields of space the ashes of humanity, frozen to its icy surfaces. No thought will ever again rise toward the infinite from the bosom of this dead world, where the soul of man has dared so much."

What a very grim, truly horrible and foreboding picture—all predicated on a dying sun—and all perfectly possible if it is granted that some day the sun will lose its heat.

Will the sun eventually burn itself out? We know that evolution of stars is a fact; that they begin as a cold, nebulous mass, becoming dull red and denser with contraction; that the next stage is intensely hot, the star becoming blue-white in color; and that then the star cools off to yellow, to red, and then finally becomes dark and cold. We see stars in the heavens in all of these stages of evolution and we know that our sun is a star in the yellow stage—just beginning to cool—and that some day it will turn to dull red, and eventually become dark and cold. This catastrophe seems inevitable in the light of our present knowledge. How fortunate it is that the climate of the past points to a continued "uniformity" of radiation from the sun for many future millions of years.

Almost as surprising as this usual uniformity are the notable climatic variations and fluctuations that can be proven to have occurred by evidence preserved in the rocks, as well as by the fossilized remains of plants and animals These departures from the normal type of climate are of particular interest for it was during such critical periods that the pulse of evolution was quickened and many new forms of life developed.

When an attempt is made to picture climatic fluctuations of the past, the question naturally arises as to whether a study of present-day climates, and their effects on organic and inorganic matter, really give trustworthy clues to the climates of millions of years ago. And for the same reason, one may wonder if all of nature's past actions are reflected in the world about us in such a way as to be obvious.

For instance, if the present climate was like that of the Jurassic, palm trees and coral reefs would be flourishing at the North Pole and frozen water would be a world-wide curiosity. Under these conditions, would any scientist, from his knowledge of the properties of ice obtained in the laboratory, be inspired to suggest the great glacial periods of the Permian and the Pleistocene? And who would believe him if he did? It is indeed fortunate that we are living in the last stages of a great Ice Age and can thus see a multitude of evidences of glaciation.

It would seem, then, that present climates and their effects should furnish a key to the past if they are rightly interpreted; but this employment of analogy, useful as it is, should be made with care.

Climatic clues or geologic thermometers

Of the many criteria for geologic climates that have been suggested from time to time, the following are the most helpful:

Dry Climate—Desert Type

Evidence that wind has been the major transporting and depositing agent is frequently preserved by rounding of the smaller sand grains (70 mesh and less)

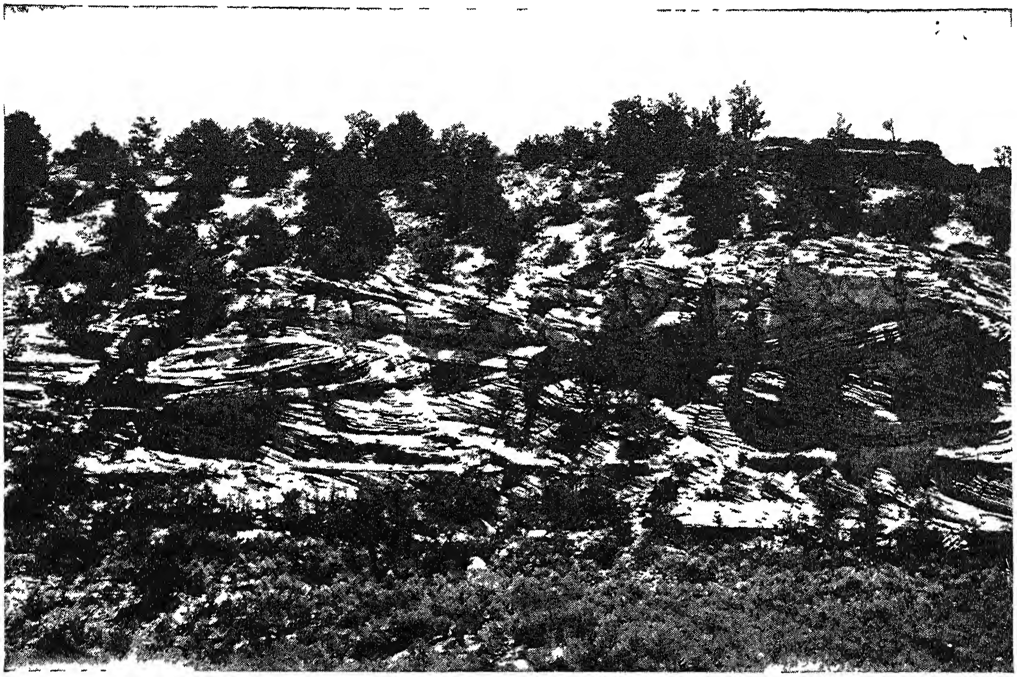


FIG I
Cross bedding in a white sandstone that was formed by wind action in a dry climate (Courtesy H Ries).

because of abrasion and the lack of a protecting film of absorbed water which usually prevents rounding of small particles in water-laid sediments; by frosting of the surfaces of sand grains resulting from continual bumping of dry surfaces, which is in direct contrast to water-laid deposits where the surfaces of sand grains are usually bright and glistening; and by distinctive wedge-like cross-bedding (Fig. 1) in many directions over large areas, a type of bedding which is developed in water-laid deposits only locally.

There is little if any carbonaceous material preserved in sediments formed in an arid environment, and the colors are usually light, although occasionally yellows, reds and dark colors may be present.

Most thick deposits of salt and gypsum point to aridity, with evaporation exceeding precipitation. It should be remembered, however, that aridity does not necessarily mean warmth, and some very arid regions of the present are developed in a cold climate. Moreover, gypsum may be occasionally formed by alteration of limestone, and in this case it has no significance as an indication of the climate existing at that time.

Red beds were formerly thought to be evidence of an arid or semi-arid climate. This is true for many red bed deposits, but very deep red soils are now being produced by the weathering of certain rocks under a covering of tropical and sub-tropical vegetation. If such a soil is transported and deposited under conditions which prevent the iron from being reduced to non-red compounds, a "red bed" sediment will be formed under climatic conditions very different from an arid environment

Warm-Moist Climate

Chemical weathering of rocks and minerals is at a maximum in a warm, moist climate; for instance, feldspar, the commonest mineral in the earth's crust, is changed to clay (Fig. 2) In arid and frigid climates, feldspar remains unaltered for a much longer period, so the freshness of the grains serves as a valuable guide.

FIG 2
A white clay that has been formed by the chemical weathering of a feldspar rock (Courtesy H Ries)

Vegetation flourishes in a warm, moist climate (Fig. 3) and, as a result, the colors of sediments formed in this environment are usually various shades of gray to black. Coal beds grade into deposits that give every indication of plenty of moisture. Moreover, the plant remains preserved in coal point to a temperate or even a fairly warm climate. In this connection it is obvious that, while growth is very rapid in a warm, moist climate, decay is also at a maximum; thus, although growth is slower in a somewhat colder climate, the arrest of decay may give more rapid accumulation and better preservation of coal deposits (Fig. 4).

FIG. 3. TYPICAL VEGETATION OF THE COAL AGE.

Fossilized forms of warmth-loving types of life, such as butterflies, reptiles, earthworms, mammals that are very ornate and highly specialized, palm trees, cycads, tree-ferns, sponges, snails, etc., are usually excellent climatic thermometers (Fig. 5). Of course, these fossilized forms should be used with care since adaptation to slowly changing climatic conditions may occa-

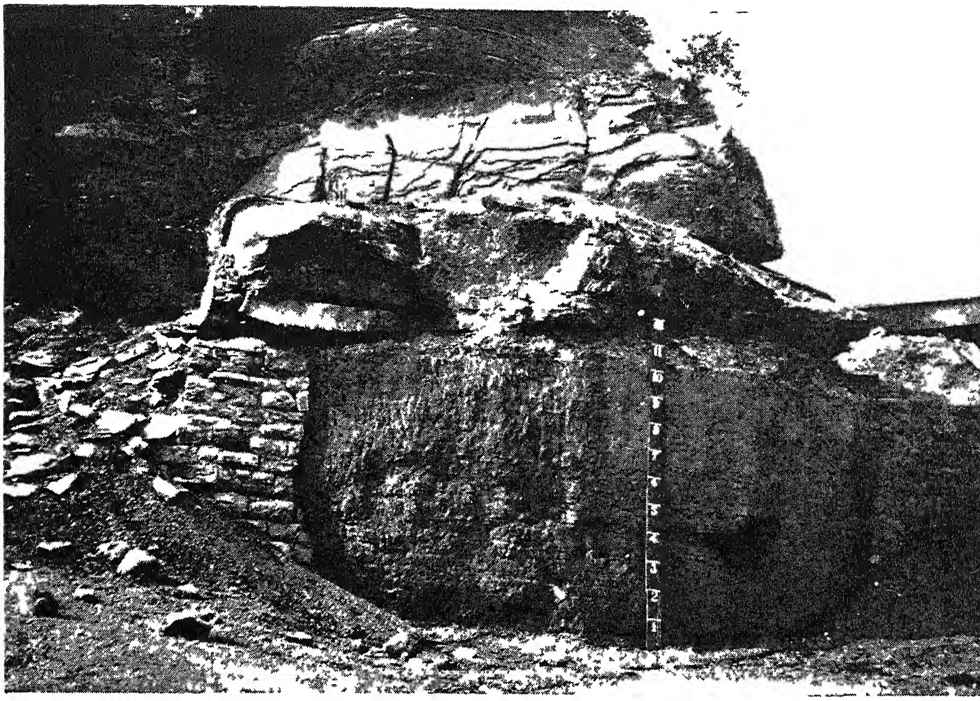


FIG 4
An exposure of a coal seam ten feet thick which is overlaid by sandstones and shales (Courtesy H Ries)

sionally permit a warmth-loving species to exist in a markedly different environment. For example, living elephants and rhinoceroses do best where it is warm, but the mammoth and the woolly rhinoceros flourished in a cold climate.

Thick beds of limestone formed by reef-building corals indicate warm climate because all of the present colony corals live in warm seas. However, all of the species of reef-building corals that made up the ancient limestones are extinct and we cannot, of course, be positive that they were as definitely restricted to warm seas as their living descendants

Cold Climates

Glacial deposits with their characteristic lack of sorting and the presence of boulder-clay and striated boulders, are reliable indicators of cold climate In addition, the finding of fossilized forms of certain hardy vegetation, as the Glossopteris flora (Fig. 6), point to climate such as exists on the frozen tundras of Siberia.

Ancient climates

In spite of the uncertainty of many of the above criteria when considered separately, their agreement when taken as a group, together with all of the other available evidence, is so definite that a fairly reliable picture of the climates of the past may be constructed.

For convenience, climates may be divided into warm and glacial. We are now living in a glacial period, which fortunately is not at its maximum. The warm periods, during which a genial climate extended from pole to pole, have been the rule throughout the greater part of earth history; and in the best developed of these warm periods, glaciers were unknown.

Without exception, warm climates were associated with low relief of the land, and the continental areas were greatly reduced as a result of flooding by shallow seas. Broad, rounded hills, instead of the mountainous topography of today, was the characteristic feature, and broad

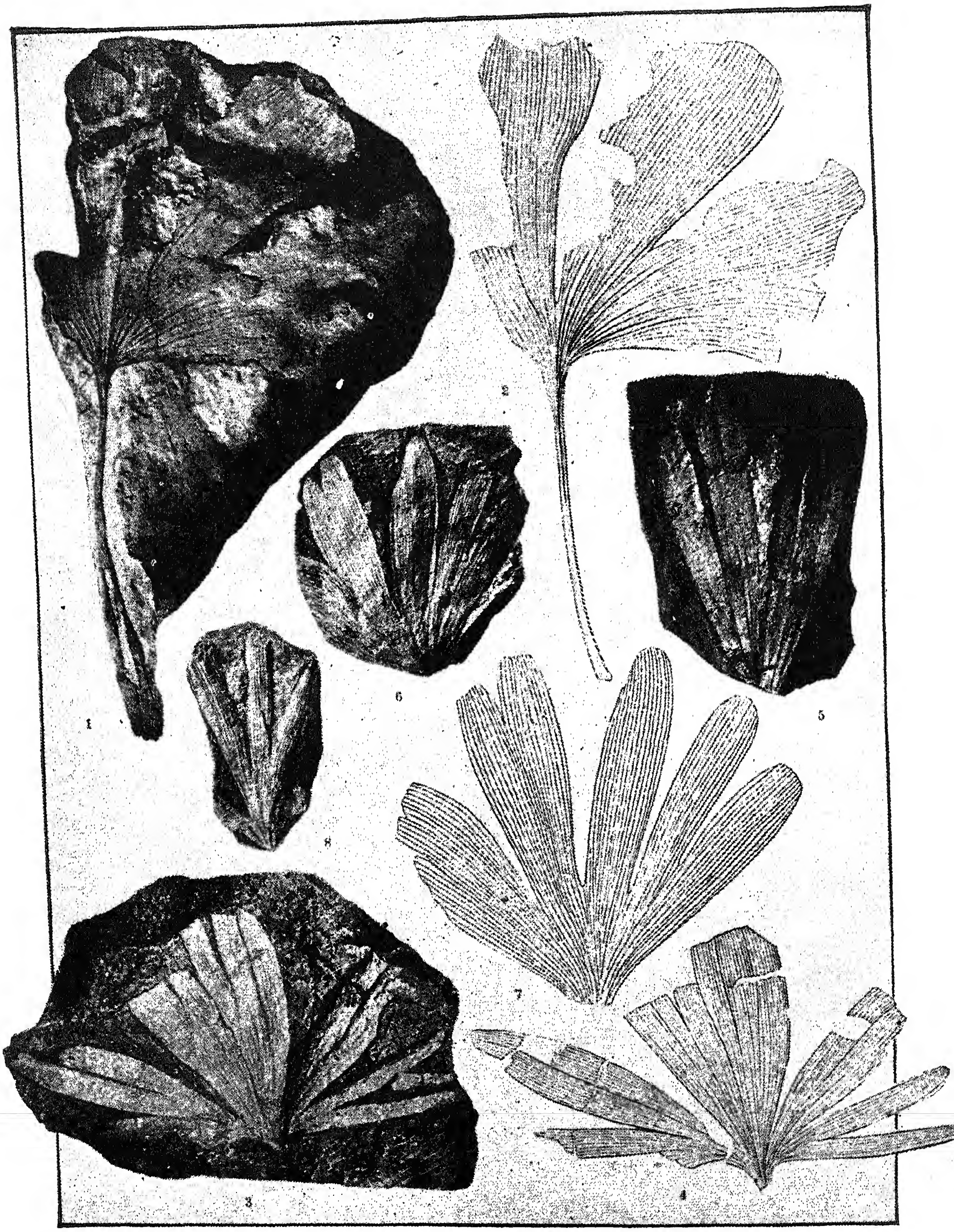


FIG. 5.

Fossilized fragments of gingkos, which indicate a warm climate. They occur in beds of Jurassic age when the climate was warm from pole to pole (Photo U. S. Geol. Survey).

oceans extended through wide channels from pole to pole. Throughout the greater part of earth history these conditions prevailed, and at such times New York had a sub-tropic climate while Greenland had a warm to temperate climate.

Deserts have always existed, but during the usual warm period they were greatly

expanded, extending from the equator, far into the present temperate zones. One of the most momentous steps in the development of life was brought about in this widespread desert environment—the origin of air-breathing vertebrates.

The evidence for a widespread warm climate, with such small differences from pole to pole, presents a real difficulty As long as the inclination of the earth's axis remains as it is today, the tropics will receive more heat than the middle latitudes, and they more than the poles. There is no indication that the inclination of the earth's axis has ever been different than it is now, so this usual relative uniformity of climate from pole to pole, is an enigma.

Interspersed in the usual warm period, the records show that the earth has passed through seven glacial periods—four of major severity in Early Pre-Cambrian, Late Pre-Cambrian, Permian, and Pleistocene; and three minor periods in the Silurian, Triassic, and Cretaceous. Of these seven glacial periods, the most recent or Pleistocene Ice Age naturally furnishes the best data, so this may be used to represent a typical glacial period.

The retreat of the last great ice sheet began some 25,000 to 30,000 years ago, and in fact it is still in progress, because the climate of today is more rigorous than it was during the usual warm period. In this connection, it must be remembered that an Ice Age is a complex of climatic fluctuations of great magnitude, rather than a simple refrigeration caused by the accumulation of enormous masses of ice in the polar regions, followed by a slow shrinkage of the glaciers as the climate ameliorated. Indeed, the Pleistocene glaciation, which extended through at least 150,000 years, consisted of several periods of extremely cold climate separated by inter-glacial periods when the climate was really warmer than it is now.

During these warm inter-glacial periods saber-toothed tigers, camels and tapirs were abundant in Alaska. The fossil remains of the sea-cow have been found as far north as New Jersey; and inter-glacial deposits in England contain the remains

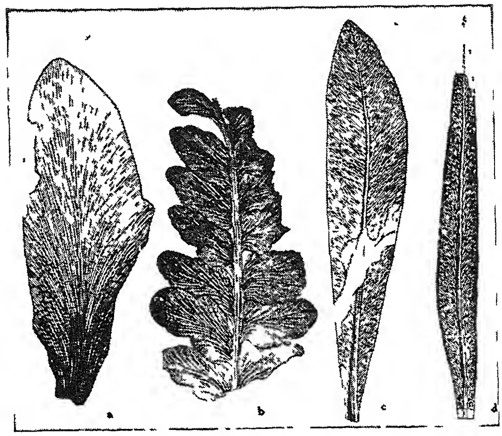


FIG 6

These specimens of glossopteris flora indicate a cold climate

of the lion and hippopotamus, along with those of man. Many scientists think that there is evidence for three or more inter-glacial periods, and there is no question that the Ice Age consisted of at least two major advances and retreats of the ice, separated by a warm inter-glacial period that lasted from 3 to 5 times longer than did true glacial conditions

Strange as it may seem, therefore, we are now living in an Ice Age and no one knows whether our climate is inter-glacial, in which case, although it may get warmer for some thousands of years, the ice will eventually over-ride a large part of the continents again; or whether the Ice Age is really departing, in which case the climate will be that of the usual warm period for some millions of years.

Cause of climatic variation

Undoubtedly, climate is controlled by the combined effects of terrestrial and solar agencies. The climate of the warm periods represents an elapsed time of hundreds of millions of years during which the earth received just about the same amount of radiant energy from the sun, and during which this heat was distributed over the earth's surface rather uniformly.

In contrast to this, glacial climates represent periods during which the earth either received less radiant energy from the sun, or, if the earth's heat supply remained constant, it was distributed by

oceanic and atmospheric circulation, so that the polar regions did not receive their share. Of course, both terrestrial and solar influences are operating all the time, and the cause of an Ice Age should be the result of their combined effects.

The real difference between the present climates at the poles and the equator is that along the equator water is water, while at the poles water is ice. Or, putting this in a slightly different way, there probably was a difference of 40 to 50 degrees centigrade in the average temperature at the polar regions, between the usual warm period and an Ice Age. A considerable part of this difference of 40 to 50 degrees may be accounted for by the cooling action of the ice cap itself; that is, the chilling effect increases more rapidly than does the mass of the ice—double the size of the ice cap, and the chilling effect should be at least four times greater. Thus, if the temperature of the ocean water at the poles is lowered only one degree below freezing, an ice cap will form, and, because of a rapid chilling effect as its size increases, the ultimate temperature of the atmosphere in that area might well be 20 degrees below freezing, all brought about by an initial drop of one degree below freezing. If this reasoning is true, the actual temperature difference between the warm periods and glacial climates might be only a few degrees, rather than 40 or 50 degrees.

Perhaps the two worst stumbling-blocks which any adequate explanation of the cause of an Ice Age must hurdle are: (1) the relatively long, warm, inter-glacial periods; and (2) the suddenness with which glaciation appears, because the fossil forms that lived just prior to a glacial period give no warning of the approaching catastrophe.

It is, of course, well established that climate is modified by the relief and elevation of a region. The more radiation from the earth can be retarded, the warmer will be the climate. In this storing of heat, the water vapor clouds of the atmosphere play a chief part by letting the heat rays from the sun through, and retarding radiation from the earth—much like the glass on a hot-bed. This will work best over low-land country, and if all of the earth's surface had a low relief, this effect would be at a maximum, and the climate would be warm.

Mountains and highlands act like holes in a hot-house glass; radiation is greatly increased and the rising of warm air and the sinking of cold currents is accelerated, thus chilling everything within a wide radius. These factors tend to give plenty of snow, and insulation, radiation and reflection take place on snow fields in such a way that the heat from the sun is used only to a small degree. Thus, a lowering of the temperature is caused far beyond the boundaries of the snow-field itself.

During the most severe climate of a glacial period an immense amount of ocean water is locked up on the land as ice, and consequently sea-level falls all over the world, perhaps as much as two or three hundred feet. This, of course, would add to the relief of the land and would also reduce the influence of ocean currents so that the net result would be a colder average climate for the whole earth.

It is not an accident that the continents today have a much higher relief than they had throughout most of geologic time—and that we are still in an Ice Age climate. There seems to be little question that a mountain revolution of major proportions is sufficient cause to modify local climates very greatly and even to produce a general lowering of the temperature all over the world. However, the elevation of a mountain is a relatively rapid event compared to its erosion and reduction to a low-land. That is, its influence on climate would disappear slowly and would lead to a long-lived climate of relative severity. Therefore it would be difficult, if not impossible, to account for warm inter-glacial periods by using mountain uplifts as the sole cause of an Ice Age. That they may explain the big periodic swings of climate is perhaps true, but something else is needed to work with mountain uplifts and account for the important complex fluctuations which

characterize a glacial period. Moreover, the uplifting of the Sierra Nevada and Rocky Mountains did not bring on glacial conditions, although they are revolutions of major importance.

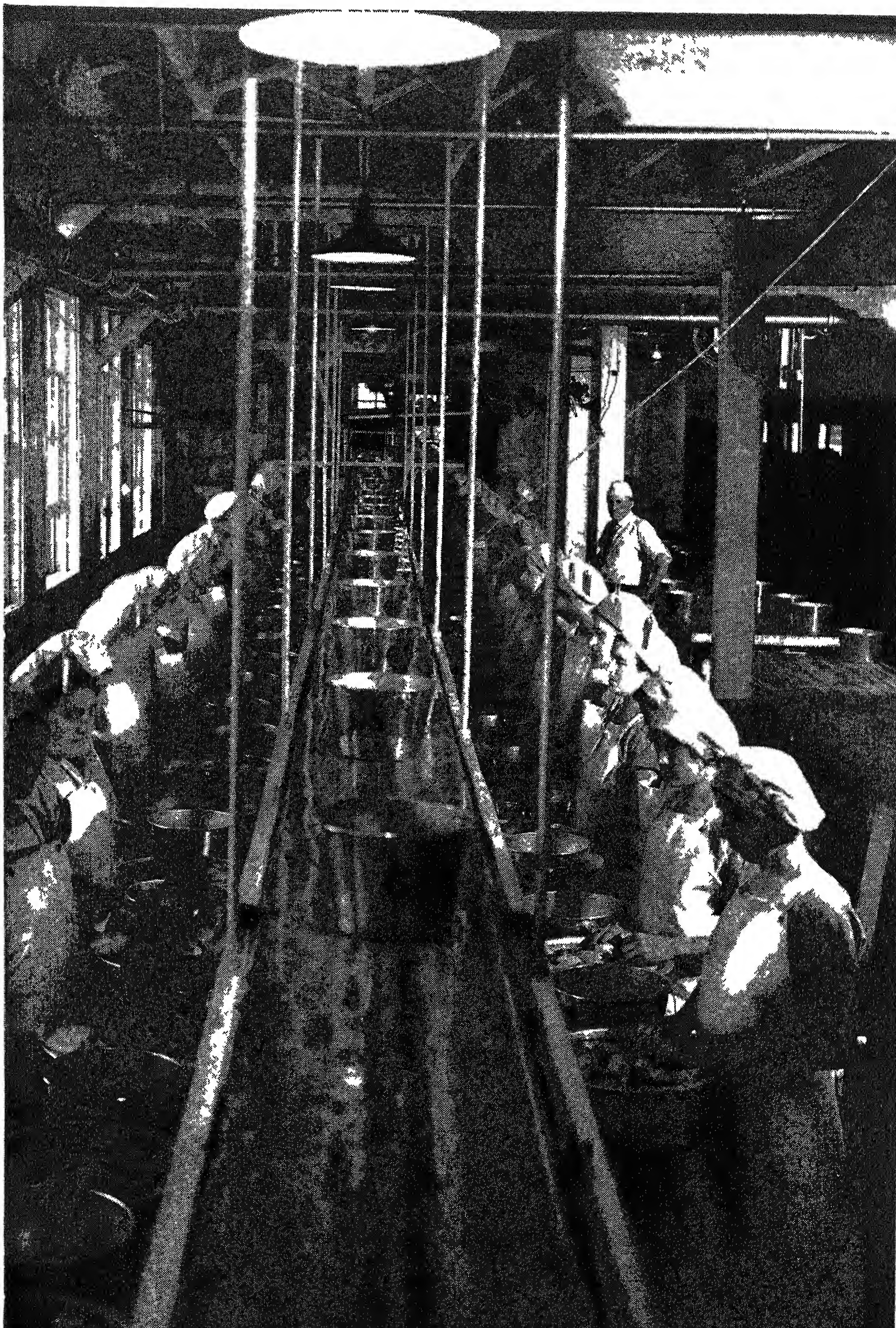
Contributing factors that may affect climates are: variations in the amount of carbon dioxide in the atmosphere, increase in the amount of volcanic dust in the atmosphere, eccentricity of the earth's orbit, a possible reversal of the present deep-sea circulation, and sun-spot activity. Aside from the last, these factors are thought to have been of minor importance.

During sun-spot activity, it has been demonstrated that the energy given off by the sun is greatly increased, and it is only reasonable to infer that this is reflected in the climate on the earth. When sun-spots are most pronounced it might appear that the climate on the earth would be warmer. However, just the opposite is true, because, during the sun-spot activity, storm conditions are ideal and a great amount of heat is blown into the upper atmosphere and lost. Indeed, sun-spot activity represents a time of heat loss and a colder climate.

Professor Huntington has suggested that active glaciation was a time of unusually well developed sun-spot formation, coupled with a widespread high-relief of the land. When the sun-spot activity died down, a mild inter-glacial period would intervene, even though the topography was still rugged. And if the formation of sun-spots became active during a period of low continental relief, the effect would not be sufficient to upset the usual warm, mild climate.

It has also been suggested that the approach of Alpha Centauri (the nearest binary star) to the sun would increase sun-spot formation and that this activity would continue as long as this star was unduly influencing the sun. Plotting the course of Alpha Centauri we find that from 50,000 to 70,000 years ago, the climate should have been warm and mild; and that 28,000 years ago there should have been active glaciation—which agrees rather well with geologic records.

In 1940, Ronald L. Ives proposed a new theory for the origin of the Permian glacial period which affected the equatorial rather than the temperate zones. Ives suggests that the earth once had another moon, which he calls Ephemeron. This moon was smaller and nearer to the earth than our present satellite, and it revolved about the equator. Tidal forces drew it even closer to the earth, and when it came within about 12,000 miles the tidal forces shattered Ephemeron into bits. These particles continued to revolve about the equator in a ring much like that around Saturn. This ring shaded the tropics from the sun's heat, thereby producing glaciation in that region, without essentially modifying the temperate zones' temperature. Eventually, due to constant collision of its particles, the ring dissipated, and the Permian glaciation likewise vanished.


National Film Board

Peeling and pitting pears in a Saint Catherines cannery, in the Niagara fruit belt of Ontario.

THE CANNING INDUSTRY

How Nature's Periodic Gifts are Preserved for a Rainy Day

THE MACHINERY USED IN FOOD PRESERVATION

PRACTICALLY all animal life is confronted with the problem of fluctuation and uncertainty in its supply of food. Not a few of the lower orders of life recognize this fact and make some provision for a rainy day. Bitter experience on the part of many of the animals with recurring periods of plenty and famine has given some of them an almost uncanny sense of thrift in the matter of storing up food. The sleek, well-fed house dog, with every prospect of being provided for in the future, carefully buries his bones or hides his excess crusts of bread in some convenient place so that in an emergency, which he cannot see but nevertheless fears, they may be recovered. With the exception of certain dwellers in tropic lands, this problem has always been an important and difficult one for man, and from very earliest times he has endeavored to preserve his excess food in time of plenty to carry him over the lean years.

We have many authentic records of great warehouses built by ancient peoples for storing foods. One of the most interesting is that unearthed at Knossus on the Island of Crete. In the ruins of this ancient palace, which dates from about 1500 B.C., are long subterranean galleries in which were placed great earthenware jars for storing food. These jars (illustrated on the next page) were sealed, no doubt, so as to exclude air and to keep the contents dry. The ancient Egyptians discovered that they could preserve the bodies of men and animals for a very long period by mummifying them, and, aided by the dry climate of the country, they accomplished marvelous results in this line. These methods, however, were not applicable to the preserving of foods, and they resorted to much more simple and well known processes. Thus many savage tribes found, by experiment, that if meat was thoroughly dried it would keep for a long time, and that smoking and salting meats and fish produced a similar effect. The art of pickling in salt or vinegar and of preserving fruits in sugar is a very ancient practice, though the chemical reasons for this phenomenon are of comparatively recent discovery. The science of preserving foods and the art of making cheap and efficient containers for preserved foods appears to be a modern achievement.

Modern canning dates from the time of Napoleon. The French government near the end of the eighteenth century, appreciating the economic gain from improved methods of preserving foodstuffs, particularly for military stores, offered a prize of 12,000 francs for the invention of a better system than those then in use. This was a large sum of money in those times, and the competition was keen. Among the many experimenters was Nicholas Appert, a confectioner, brewer and distiller. Appert worked from 1795 to 1804 before he developed a successful process consisting in heating the product and sealing it in an air-tight container. The results obtained were so promising that he persisted in his experiments, using many different materials, and had so perfected the art by 1810 that the French government published his monograph upon the "Art of Preserving Animal and Vegetable Substances," and announced that he was entitled to the prize.

Appert packed his products in glass or china containers, added sufficient water to cover them, inserted the corks and placed the containers in a bath of water which was gradually heated to the boiling point and kept at that temperature for varying lengths of time depending upon the nature of the product to be preserved. He is said to have attained a temperature of from 190 to 200° F. in the interior of his bottles, the maximum attainable being that of boiling water, or 212°.

According to the somewhat meager records of Appert's experiments, it appears that he preserved eggs so perfectly that even after some time they could be used for any purposes that normally required fresh eggs. Appert may have prepared eggs by partially cooking them and thus preserved them for a considerable length of time. Today eggs packed in water glass (a substance consisting of sodium silicate and resembling glass) without processing may, if of good quality, be held for a long time. Appert also used glass and china jars entirely for his products and these were long considered the best containers for sterilized foods But they are fragile and expensive and it was not until the invention of the American tin can that modern canning was fully developed. Appert, however, is regarded as the father of the industry which has solved the ancient problem of preserving the excess of food in times of plenty against the time of want, though he is said to have died in poverty — the unhappy fate of many of the world's greatest benefactors.

Photo Prof E P Andrews, Cornell University

HUGE EARTHENWARE JARS FOUND AT KNOSSUS, IN CRETE

These are believed to have been used to store food The great palace was built about 1500 B C

About 1807 an Englishman named Saddington described a method of preserving foods very much like that developed by Appert. Saddington's process was to place the fruit to be preserved in glass bottles loosely corked and to put them in a water bath heated to 165° F. for a period of one hour. Boiling water was then added to cover the fruit, the corks were driven in tightly and the bottles laid upon their sides to keep the corks moist. As Saddington did not claim originality for his method it is supposed that he obtained the general principles when traveling in France.

Neither Appert nor any of the pioneers in this field knew the true reasons for the success of his procedure The most obvious conclusion, of course, was that the preservative effect was due to the exclusion of the air, an idea corroborated by the experiment of heating the material to be preserved in a separate vessel and then pouring it into the bottles. with unfavorable results. All of those who followed Appert held to this theory and much care was used to "vent" the cans while hot, thus allowing the air to escape.

The French government commissioned the great chemist Gay-Lussac to investigate the matter, and he reported that food spoiled because of oxidation changes and that by the exclusion of the air these changes were prevented in bottled goods like Appert's.

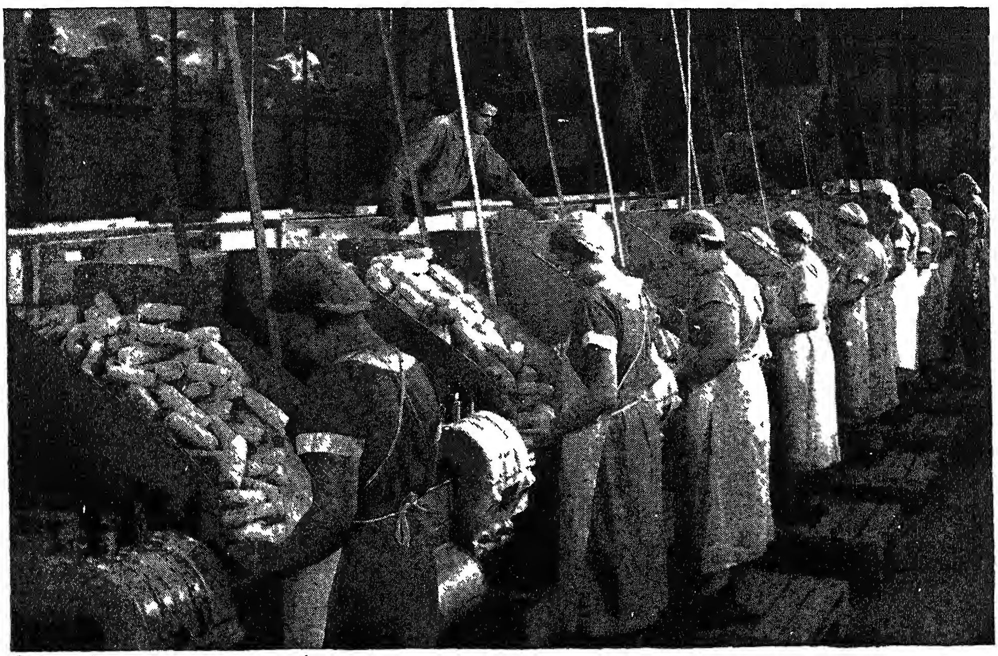
This theory was, therefore, widely accepted until the work of Louis Pasteur, the famous French investigator, proved beyond doubt that decay was caused by living microörganisms.

It is now generally accepted by men of science that air plays no very important part in the process of decay except as a carrier of these living organisms which are commonly and somewhat indiscriminately spoken of as microbes, germs, microörganisms or bacteria.

Scientific research has proved beyond a doubt that these microorganisms exist in teeming millions and that they are present everywhere. The water we drink, the soil on which we walk, and the air we breathe are literally filled with them, although for the most part they are invisible to the naked eye. Many of them are harmless and many harmful under certain circumstances. Some of them, called "parasites", live upon live animals and plants; and some, called "saprophytes", live upon dead animals and plants, and it is this class that is of most importance in the art of preserving and canning.

These organisms which cause decay in food are divided by bacteriologists into three groups or classes: molds, yeasts and bacteria. The presence of any or all of these on food is the principal cause of its spoiling, and the secret of successfully preserving it is, therefore, to kill all of the organisms that may be already upon the food and to prevent any others from coming in contact with it. A description of the several methods used in preserving foods will make the relation of these organisms to the problem more clear. These methods are by drying, by the use of preservatives, by applying cold or heat.

The method of drying foods is, as has been noted, very ancient and is still much practised. Molds, yeast and bacteria cannot readily develop in very dry surroundings, which accounts in a large degree, no doubt, for the great success of the Egyptian mummifying processes. Many foods, such as certain nuts, dry sufficiently in the natural process of ripening to keep for a long time; others, such as raisin grapes, must be dried with greater care. It is found that the action of smoke and other disinfecting fumes is of great assistance in preserving in a dry state such foods as meats and fish. Dried foods must be kept in a dry place, or sealed from the air, if they are to be prevented from taking up moisture and thus permit molds and bacteria to begin their work.



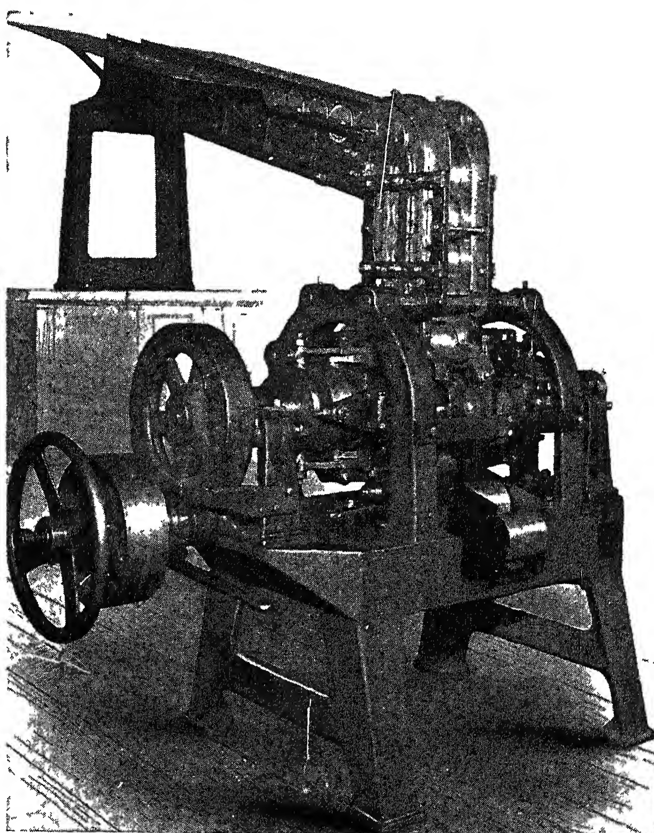
Courtesy Food Machinery Corporation

CORN-CUTTING MACHINES AT WORK

These modern machines can turn out either "whole kernel" or "cream style" work.

Every housewife knows that sugar, salt, vinegar and certain spices are very effective in preserving foods. Yeasts and bacteria cannot readily grow in their presence, but mold may take root where these others cannot. Jellies and pickles, therefore, may resist yeast and bacteria, but mold readily forms on the surface unless it is protected by paraffin or some other medium for excluding the air. In the use of some preservatives lactic acid or other acids are sometimes formed which arrest decay. The preservation of ensilage is largely due to the formation of such preventive agents within the food itself.

Pasteur's discoveries naturally set experimenters to work to find chemical agents that would kill those microbes that infest food and yet leave the food in fit condition for human use. Boric acid, borax, salicylic acid, formaldehyde, benzoate of soda, sulphurous acid and sulphites have all been used for this purpose. There has been much discussion as to the harmful effects of these antiseptic preservatives and many attribute the increase in stomach irritations to their use. The trend of opinion is against their use and the modern pure-food laws have put a ban upon most of them. They are not used in commercially canned foods. Certainly we are in need of more information regarding the use of antiseptics as food preservers and at present the burden of proof is upon those that persist in using them.



Courtesy E. W. Bliss Co.

AUTOMATIC CLOSING MACHINE

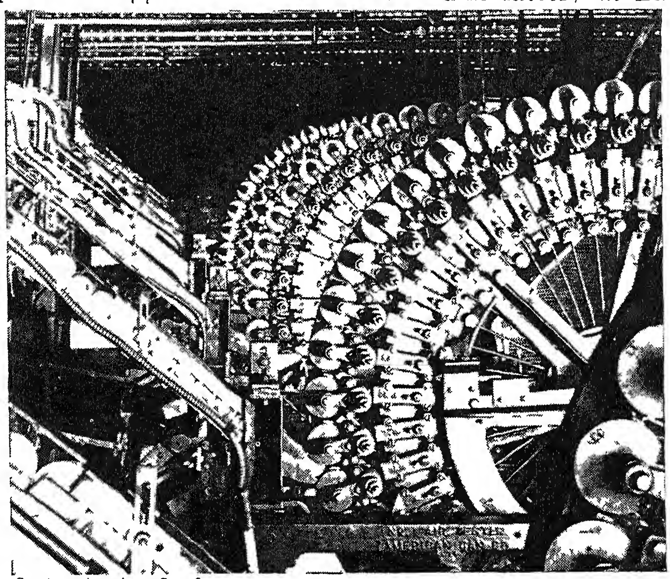
This machine puts the heads on the bodies of the cans at the rate of 140 a minute The cans are fed into it by gravity, the operator standing on the platform at the back.

Cold will arrest but will not kill these troublesome organisms and practically all foods can be preserved for a long time if kept in a low temperature. Some foods can be kept indefinitely if frozen solid, and meats may be so kept for a long time, often with an improvement in tenderness and flavor. There is a limit, however, to the time that most foods can be kept in cold storage, and however efficient the methods employed may be, they do not answer the great general demand for a process which will preserve foods indefinitely, in any place, any climate and any temperature. The answer to this demand is found in the canning process using heat to destroy all organisms.

For all these organisms are destroyed by heat if the temperature is sufficiently high. Appert's great discovery, though he did not realize it, lay simply in the fact that he heated the food high enough to kill most microbes and in such a manner that it could be sealed up while thus sterilized so that no other organisms could gain access to it. This is the one great principle in successful canning whether in the home or in the largest commercial factory. Food is sometimes pasteurized, that is, it is heated

till some, but not all, of the organisms are destroyed. This process is often applied to milk and other foods which might suffer undesirable change if heated to the point where perfect sterilization would occur. It usually prolongs the time during which the food remains edible. When the temperature is carried to the point of perfect sterilization the food is ordinarily cooked, at least to some extent.

Next in importance to the scientific theory of canning is the practical problem of the container or receptacle in which the food shall be packed. Appert and other pioneers, as we have seen, used glass and pottery containers, and for home canning and for certain factory products, these are still much used. But for the majority of products the tin can is the most widely used. The tin container was invented by Peter Durand in England about 1807. In its early form it was a crude affair made by hand and the putting on of the head by hand was cumbersome and unsanitary. The history of canning is largely that of the development of can-making machinery, which originated here in America, the country which still leads all others in the can and canning industries.



Courtesy American Can Company

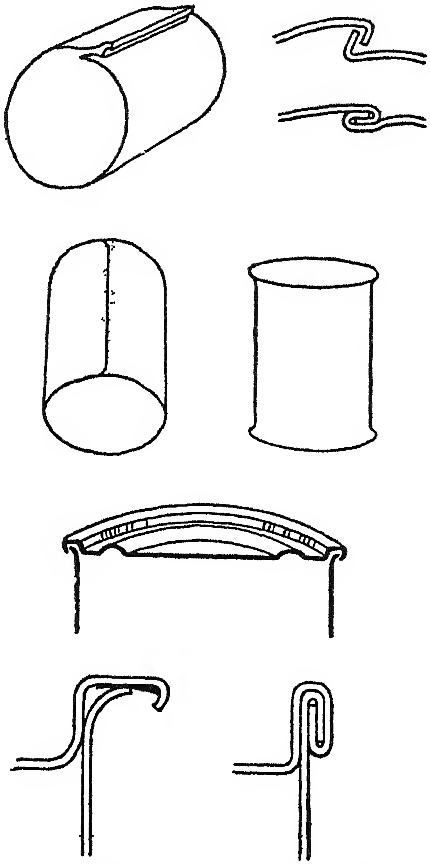
A BATTERY OF CAN TESTERS

Cans are shown entering the testing machines from the left. The testers are used at the end of production lines to provide automatic inspection to make sure that every can leaving the line is free from leaks. A leaky can is automatically ejected.

Canning as a commercial venture was introduced into this country in 1819. In that year Ezra Dagget and Thomas Kensett, who had learned the art in England, began to can salmon, lobsters and oysters in New York. In 1820 William Underwood and Charles Mitchell are credited with canning fruits in Boston. The firm of Underwood has been in continuous operation since that time and is the oldest packing house in America. The tin containers used by Underwood were called "canisters", a name still in use for certain kinds of containers. The word "can" is, no doubt, an abbreviation of "canister", in fact it is so abbreviated in the old Underwood commercial accounts. It is interesting to note that nearly all the early canning factories began on fish products. The first oyster cannery in Baltimore was established in 1840, the first sardine factory at Eastport, Maine, in 1841, the first cannery on the Pacific Coast was opened in 1850 and the first fish cannery in Alaska in 1878.

These pioneer packers began with the hand-made cans that have been described, every packer making his own. By 1865 a few manufacturing tools had been invented for stamping out the heads and bottoms, and at that time a good workman could make about 150 cans in a day. Then came an era of invention of can-making machinery. In 1877 the first improved machine for making side seams enabled a workman to make 1200 seams in a day and by 1880 a man and a boy could make 1500 completed cans in a day, with the machinery then in use. These new machines were bitterly fought by the workmen and were put into use only by the most strenuous efforts of the manufacturers. After 1890 mechanical progress was very rapid and today the machinery by which cans are made is almost entirely automatic.

Rapid strides were made in the late 19th century in the manufacture of the all-soldered can which is still used for evaporated milk and sometimes for paint. This all-soldered construction consists of a cylinder



MAKING A CYLINDRICAL TIN CAN

Small pieces of tin plate called body blanks are fed into a machine called a body maker. First it notches the blanks at each corner of one end to remove part of the metal. At the other end it cuts slits so that the end can be folded back in a later operation. Each end of the blank is then turned back to form a narrow hook, and so that the ends, when turned in opposite directions will lock when the blank is bent to form a cylinder. Next, the machine applies flux for soldering. The seam, made by bringing the hooks together is "bumped" tight. After a second flux bath, solder is applied. Both flux and solder are applied only on the outside of the can. A flange is put on the rim. The bottom is, of course, put on by the can manufacturer. The top is sealed on (after the can is filled) by the canner who uses the same method shown in the drawings. Ends for the cans are punched from sheets of tin plate and a machine curls the rims. By means of a machine called a double seamer, the curled rim and the flange of the body are folded tightly together with rubber composition between them, thus requiring no solder on top or bottom of the can.

upon which two ends having snug fitting flanges are telescoped. All seams are sealed by soldering. The cans are made on lines of machinery and a single line produces over 300 cans per minute. Both ends are applied at the factory, and the cans are filled through a hole in the top which is later closed by soldering.

The greatest advance in the art of can-making was the development of the sanitary can. The structure of this can is shown in the drawings. The side seam is of soldered lock and lap construction. The end seams are double, being interlocked hooks of the body and end. This double seam is produced by spinning the metal together in a double seamer. A layer of rubber-like compound forms a gasket and renders the seam hermetic. The factory applies only the bottom end. The top is applied by a double seamer after the can is filled.

Cans are sometimes enameled inside to increase the attractiveness of the product and to improve the appearance of the container. Enamels in wide use are (1) sanitary or standard enamel used to prevent the fading of color with highly colored fruits, and (2) C-enamel, employed to prevent sulphide staining the containers caused by sulphur-bearing foods. The behavior of food products is diverse and other enamels are required for special products such as meat, seafood, and beer. Cans are washed before using by an automatic machine which directs strong jets of water into the can as it moves along.

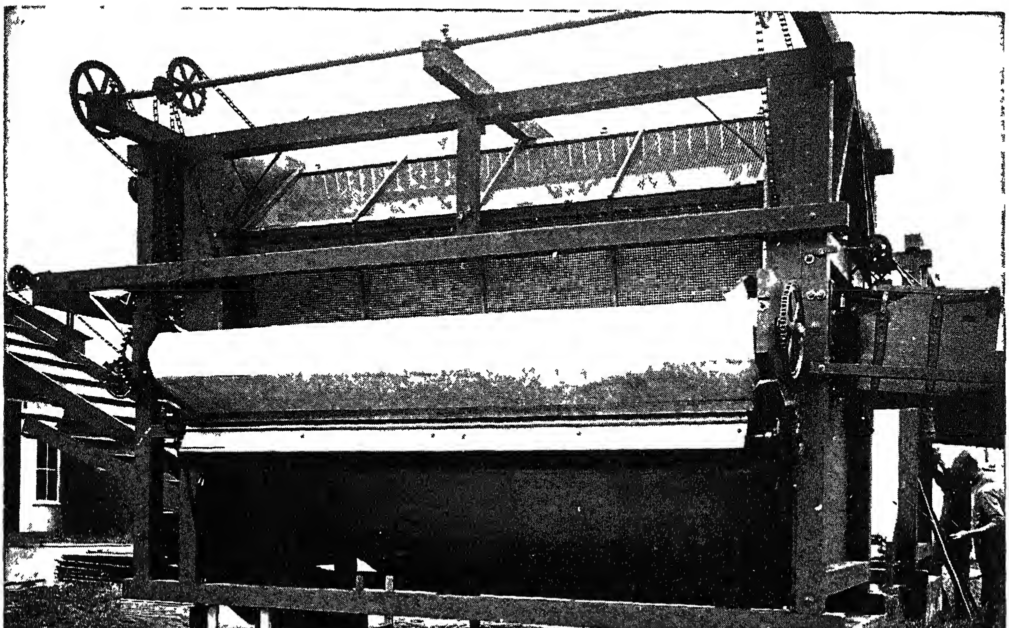
Some idea of the size of this branch of canning may be gathered from the capitalization of the American Can Company which in 1901 took over practically all the then existing can-making companies in the United States and was incorporated with a capital of $88,000,000. Since then, however, many independent plants have sprung up and it is estimated that the yearly out put of cans for processed foods only is about 15,000,000. The development of this industry, which has so greatly reduced the price of cans, made possible the application of Appert's discovery on the present gigantic scale and has made it a priceless gift to humanity.

It will be perfectly obvious that in order to obtain first-class canned goods the raw material must be selected with great care and from the very best varieties of stock.

It is important, too, that the raw material treated at any one time shall be of uniform quality and maturity. Thus a mixture of several varieties of peas cut at various stages of maturity could not be expected to produce a high grade, uniform product. On the other hand, the raw material must necessarily come from many sources and many growers, and the problem of selection is therefore a difficult one since it fixes, primarily, what is called "quality" in the product. When it is considered also that the difference of a few days in the time of gathering may make a marked difference in tenderness and flavor, it will be seen that great haste is often necessary in canning operations if high quality is to be obtained. The selection of food of any kind for canning has become an important function. The canning industry is a very wide one, and while the fundamental principles involved are the same in practically all cases, there is, necessarily, great variation in the details where there are so many kinds of product. There is also a great variety in the machinery employed, some of it being very interesting and complicated.

The following brief outline of the principal steps in canning such foods as fruit and vegetables may make the general methods clear, and later paragraphs will discuss the canning of certain special products in more detail.

After the food has been selected and has arrived at the cannery, it is "graded" both as to quality and size. Grading for quality is done by personal observation but grading for size is usually done mechanically. It is sometimes contended that grading for size is often carried to an entirely unnecessary extreme.



Courtesy Frank Hamachek

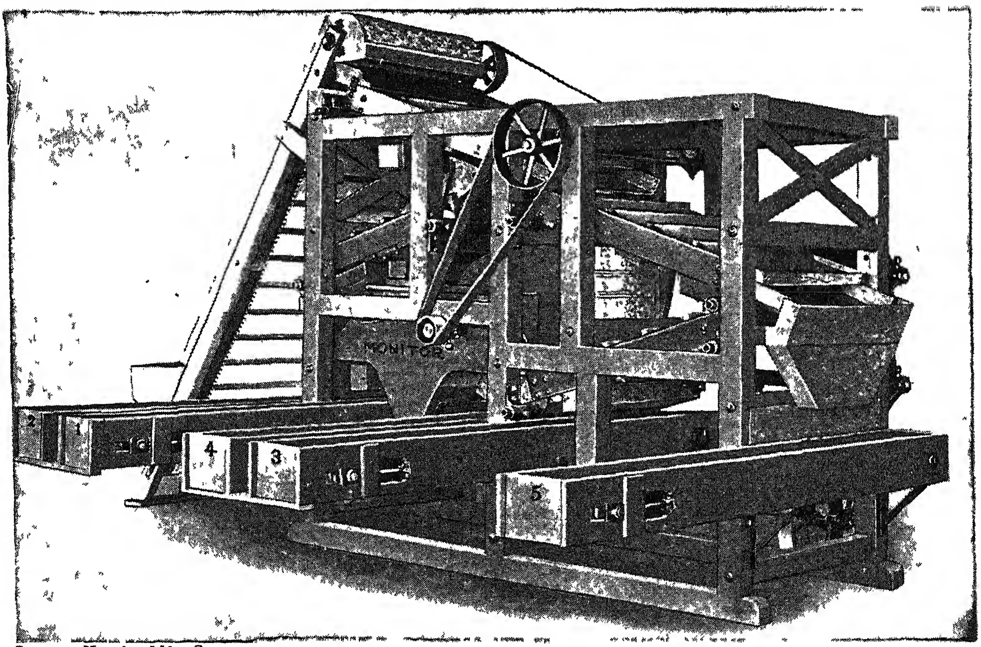
A GREEN PEA HULLER OR "VINER"

This ingenious machine separates the peas from the pods without injuring them, working something like a threshing machine.

But most people are critical about the appearance of their food and prefer, for instance, to have all their peas of fairly uniform size even though mixed sizes may taste better and be cheaper to buy. Everyone wishes to have asparagus of large and uniform size and most people are willing to pay extra for graded food. This is well shown by the fact that as high as fifteen grades of peas and peaches are regularly marketed. Some foods, however, must be graded for size by hand, but fruits and vegetables are graded by machinery.

The machinery for sizing is quite varied in appearance but depends largely upon two principles for its action. In one kind the separation is made by passing the fruit over a series of holes of different sizes. These holes may be in a revolving cylinder or in vibrating screens, the fruit or berries passing over successive sets of these holes, each set of holes screening off a size or grade. In another kind of machine the material to be graded rolls down a tapering slot, each size of product dropping through when the width of the slot permits. An ingenious apple sizer uses the principle that a given force will throw a light body farther than a heavy one. Separation for quality is usually performed by hand. In the case of green peas, however, it is known that the tender succulent ones are light and will float, while the older and harder peas will sink, and this principle is made use of in grading peas by machinery. By putting salt in the water any gradation of separation according to lightness is easily possible.

All fruits and vegetables must be carefully picked over and prepared and all defective fruit removed. Berries, plums and cherries must be stemmed, corn is husked, peas are shelled and beans have the ends snipped off. Some of these operations are performed by machinery, but others must be done by hand. After the preliminary preparation most fruits and vegetables must be carefully and thoroughly washed. Some very ingenious machines have been invented for this work and the operations include soaking, spraying and agitating, depending upon the fruit or vegetable treated and the difficulty of removing the dust. A very common type of washer is that known as the squirrel-cage. This consists of a long cylinder covered with woven wire and sometimes fitted with a spiral-shaped interior surface, so that the product to be washed is propelled from the intake to the discharge end as the drum slowly revolves. A pipe running the entire length of the inside sprays the vegetables or fruits as they tumble over and over in their advance through the cylinder. Other washers depend upon slowly rotating paddles to stir the product while it is sprayed. The amount and method of washing depend upon the material. Berries need a slight

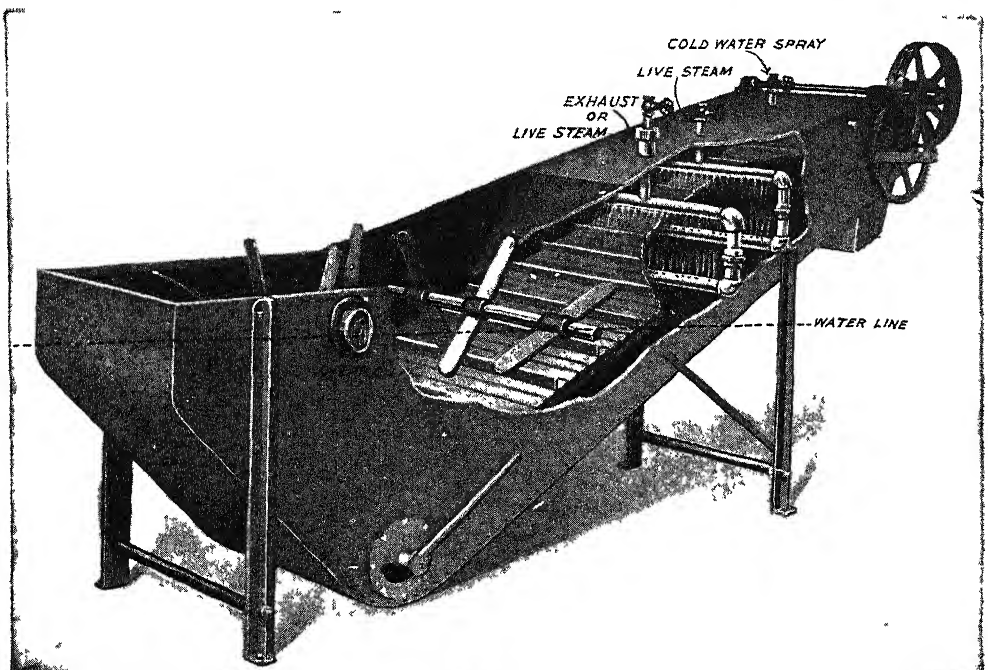


Courtesy Huntley Mfg. Co.

A STRING BEAN GRADER
This machine automatically sorts the pods into several sizes.

immersion and spraying with a fine spray, while tomatoes require small, strong jets of water to properly cleanse their exterior surfaces. After washing, many fruits and vegetables need peeling or coring: thus peaches are pitted and peeled; apples and pears are peeled and cored, and cherries are pitted, and all by machinery. A good automatic cherry pitter can pit as much as 15,000 pounds in ten hours.

Many fruits and vegetables require what is known as "blanching", and normally this is the next operation. The term is derived from the French *blanchir* in its secondary meaning of "to scald off" and not in its usual one of "to whiten". Most vegetables are blanched by being dropped into boiling water for a few minutes to soften them and remove any stickiness that they may possess. In the case of peaches, for instance, this process performed in large-scale canning by automatic machinery not unlike the cylindrical washer already described, softens them so that they pack more readily in the can and also gives them a more uniform color.



Courtesy Ayars Machine Co.

A WASHER AND SCALDER ESPECIALLY DESIGNED TO HANDLE TOMATOES

The tomatoes are stirred by the paddles in the lower part of the machine until all the dirt is removed As they pass up the traveling incline they are scalded and then cooled.

The product is now, in general, ready to be placed in the cans, though sometimes it receives another washing after blanching. Pitted fruits are washed after coming from the pitter whether they are blanched or not. Filling is done principally by automatic or semi-automatic machinery. Some of these machines accurately measure the amount that is to go into each can and place that amount in each can automatically. Others require some assistance from an operator. In general each kind of food — such as corn, peas, tomatoes string beans, milk, fish, etc. — requires a special machine and consequently there is quite a wide variety of this apparatus.

In most canning operations the cans are now "exhausted". This usually consists of passing them through a hot water bath to heat them, the main object being to drive out the air. An exhausting machine is usually a long box-like affair with a traveling chain conveyer which carries the filled cans from the filler through hot water or steam and delivers them hot to the machine which puts on the tops or caps.

Courtesy American Can Co

COOLING THE CANS

After the sterilizing or heat process, the canned product is taken directly from the retort in crates and conveyed slowly through a canal containing cold water. As the crates reach the far end of the canal, the temperature of the contents of the can has been reduced very considerably. There are other methods of cooling but this is perhaps the most commonly used

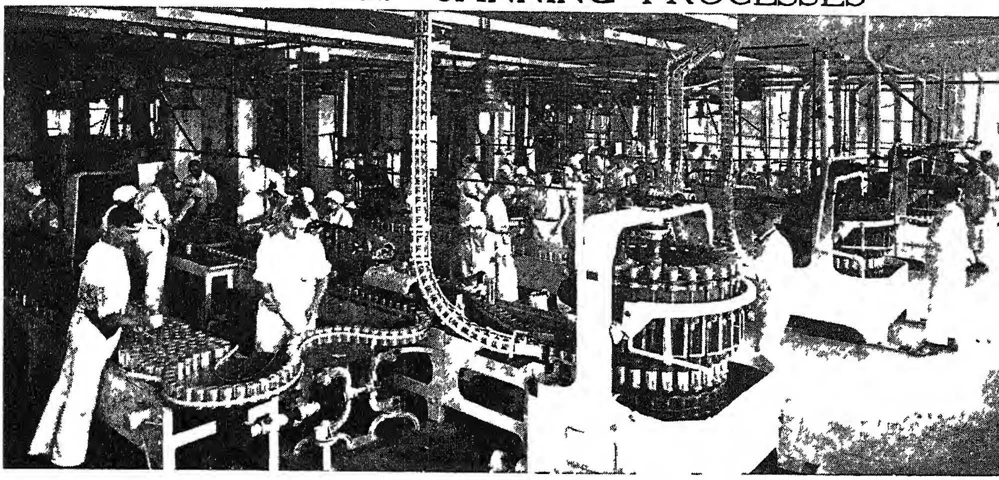
Exhausting may be accomplished by any practicable means that causes the food to be hot at the time the can is sealed or, in the case of some foods, it may be accomplished mechanically without the use of heat. This latter method involves the use of a so-called vacuum closing machine. For other products where air can be easily trapped within cavities of the food, a simple vacuum closure may not be practicable. For example, to obtain the best results with meat products such as whole or spiced ham or other tightly packed foods, a prolonged subjection of the can to vacuum is necessary. As explained above, the main object of the exhausting process is to drive out the air. The principal reasons for this are (1) to make possible the reduction of the pressure in the can during processing to a point below that which otherwise would be present and (2) to produce a vacuum in the cans after processing so that the can ends will be drawn into a normal concave position.

In modern practice, the open-top or sanitary style cylindrical can is almost universally used. Prior to 1900, tin containers used for foods were either of the old hand-soldered open-top style or of the more familiar "hole-and-cap" type. These latter were supplied to the canner together with the caps, in the center of which was a small hole or vent. Food was placed in the can and the caps sealed on by a special soldering iron. The vent hole was then closed or tipped with solder and the can processed and cooled. In modern canning the only practical use for the old type can is for evaporated and condensed milk. In fact the can manufacturers guarantee to the canner that as high as 998 sanitary cans out of 1,000 will be perfect. Closing machines for the latter type are highly automatic. This machine "double seams" the cover onto the flange of the can and turns them out ready for processing.

Processing the cans

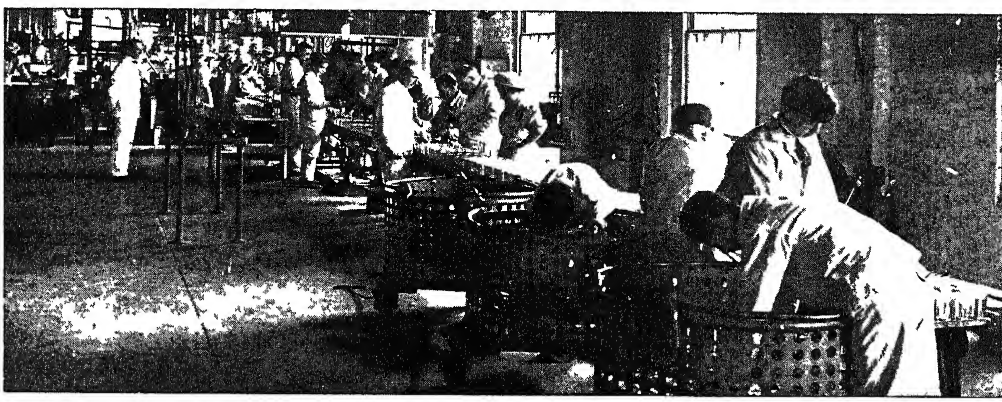
The cans are now processed. By this is meant the heat treatment which is applied for the purpose of destroying bacteria or their spores, which could grow and cause spoilage in the product if they were not destroyed. A temperature of 212° F. would kill actively growing organisms, but in some instances may not be sufficient to kill the bacterial spores. These spores may be likened to seeds and represent the resting or dormant stage of certain bacteria. In some cases they are extremely resistant to heat and effective processing calls for a temperature considerably higher than 212°. For the most part, acid products may be processed at 212° because, as a practical matter, most bacterial spores would not grow in them even if they survived the effects of the heat. In the case of low-acid products, such as corn, peas, spinach, and meats, it is customary to employ temperatures of 240° to 250°. These, therefore, must be processed under steam pressure. This is done in a closed retort or pressure cooker of a vertical type, the invention of A. K. Shriver, a Baltimore canner, and preferred by Eastern firms; or of a horizontal type favored by Pacific Coast packers, the choice depending largely on floor space, layout of plant, and daily capacity expected of each "line" of canning machinery. In the closed cooker, pressures from 5 to 15 pounds are carried corresponding to temperatures of from 220° F. to 255° F., insuring the destruction of all organisms at one application.

SOME SOUP CANNING PROCESSES



FILLING AND CAPPING SOUP CANS

Ten of these machines can fill and cap 2535 cans every minute.



FILLING THE STERILIZING BASKETS

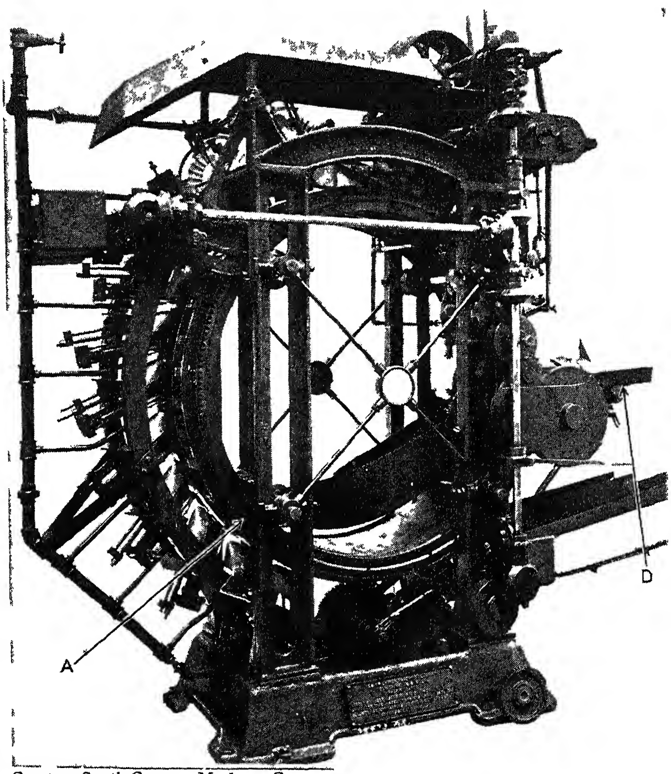
These baskets when full are placed in the processing retorts shown below.

Photos Courtesy of Joseph Campbell Co.

THE PROCESSING RETORTS

Each of these retorts will hold over 2000 soup cans of ordinary size.

These retorts are usually supplied with steam from a steam boiler and are equipped with steam gauges and other controlling devices that automatically keep the pressure, and hence the temperature, at the required point with great accuracy. In most advanced practice the steam is automatically cut off at the proper time and air and water introduced to cool the cans. It is important that the cans be cooled as soon as possible after processing as continued heating is injurious to the product. Cooling is accomplished either by cooling the pressure cooker or by taking the cans out and immersing or spraying them with water. After cooling, the cans are cleaned bright and sometimes lacquered to prevent rusting. The labels are then put on by automatic machinery and the goods are ready for boxing and shipping.



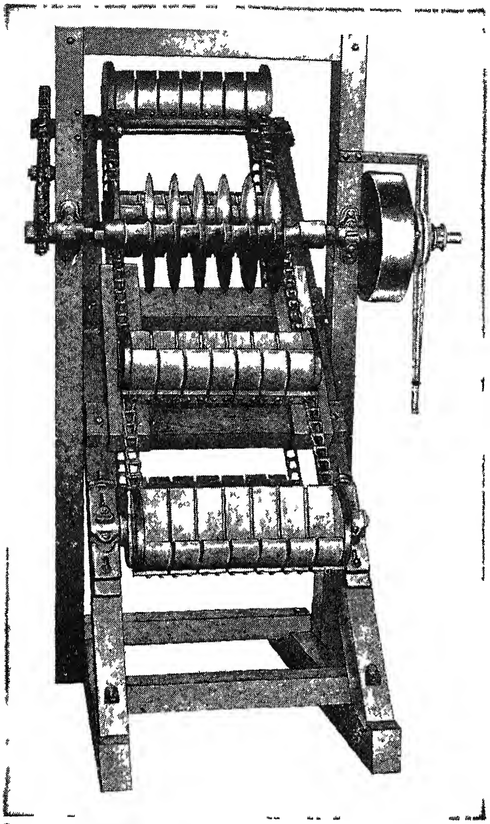
Courtesy Smith Cannery Machines Co.

IRON CHINK FOR CLEANING SALMON

The operation of the machine is entirely automatic ; it removes the head, tail, fins, entrails and blood of any salmon weighing from two to twenty pounds at the rate of sixty per minute without adjustment for the different sizes It does the work of sixty expert cannery laborers *D* is the feeding table The header attachment first removes the head from the fish, which then enters the chink tail-end first, belly up, and in the course of its journey around the large wheel *A* a set of revolving knives cut off the tail, then another set divest it of its back fins and still another of its vent, belly and gill fins , a revolving knife at the top of the circuit opens the belly, and revolving gutter wheels directly following sweep out the entrails , the sliming and washing is next done by the sliming mechanism directly opposite the point of entry of the fish Water under pressure is forced into the fish while the slimers are doing their work, which absolutely removes all refuse.

One of the most interesting canning operations is found in the salmon canneries of the Pacific Coast. These splendid food-fish abound from the Columbia River north into Alaska. The method used in catching them and the value and extent of this great industry are described elsewhere. Four of the several varieties of salmon are much used for canning, namely, the Chinook or king; the blue-back or sock-eye, the silver-sides; and the hump-back The color of the flesh of the several varieties varies from pale pink to a rich reddish color and, while preference is usually for the latter, the lighter colored meats are often really superior In the early days practically all of the labor of canning salmon was performed by hand, and as much of the preliminary work was dirty and disagreeable, the only men who could be persuaded to do it were Indians and Chinamen. The labor problem was further complicated by the short season character of the work, salmon canneries operating only for a few weeks while the salmon are running up the streams to spawn.

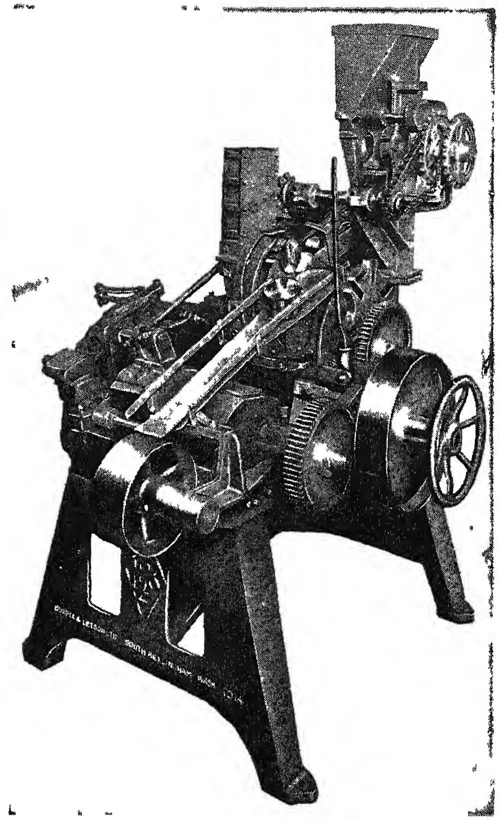
These conditions led to the invention of the "iron chink", so called from the fact that "chink" was the local name for Chinaman. The iron chink is easily the most interesting machine in the entire field of the canning industry and certainly one of the most ingenious ever invented by man. While it may look complicated, it is really very simple in operation and unlikely to get out of order.



Courtesy Burpee & Letson Ltd

A FISH "CUTTER"

The fish are carried against the revolving knives, which can be set to suit the height of the cans to be used



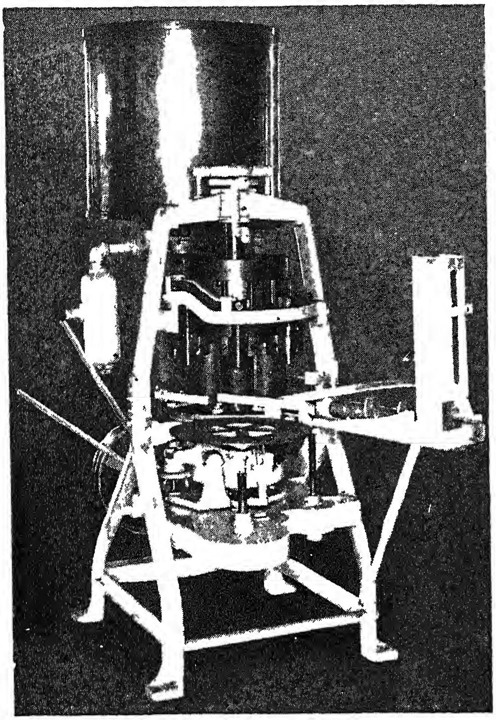
FILLING MACHINE

This is the machine used in salmon canning It automatically fills the cans and adds the proper amount of salt

After the fish leave the chink they pass into the "cutter" which cuts them in proper lengths to suit the cans used. The cutter consists of a frame which carries a number of revolving disc knives on a common spindle under which the salmon are drawn by a chain carrier. The distances between the knives are adjustable to suit the length of the can. The cut fish falls into a bin from which it is carried to the filling machine or the filling table.

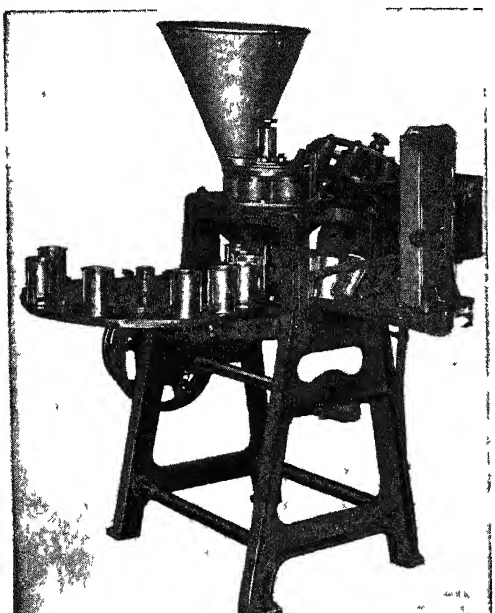
Short cans are often filled by hand but the tall cans are usually filled by an automatic machine which forces the meat into the can by means of a plunger. The cans are now washed and passed through a weighing machine which automatically rejects all that are under weight. These are returned to the fillers and brought up to weight. Sanitary or open-top cans are much used for salmon and in such a case the cans pass next to a "clinching" machine which automatically puts the top on the can and clinches it over in a few places but yet leaves it open enough to be properly exhausted. The cans are then thoroughly exhausted and passed to a double seamer which closes the top so that it is air-tight. The cans are processed in the usual manner but the exhausting and processing are longer and heavier than in the case of vegetables and fruits. Salmon canning, at one time, was a very unsavory and unsanitary process, but this is no longer so.

In a modern first-class salmon cannery, equipped with automatic machinery, there is no reason for not maintaining as good, if not better, conditions than are found in most fruit and vegetable canneries. Salmon canning has made greater progress than almost any other line of canning or packing, and it has become a very important industry.



AUTOMATIC CORN COOKER FILLER

This machine will fill 120 cans a minute The corn is heated in the large cylindrical cooker and is pushed into the cans by power-operated plungers The cans are fed into the machine automatically, from the stack supply on the right.



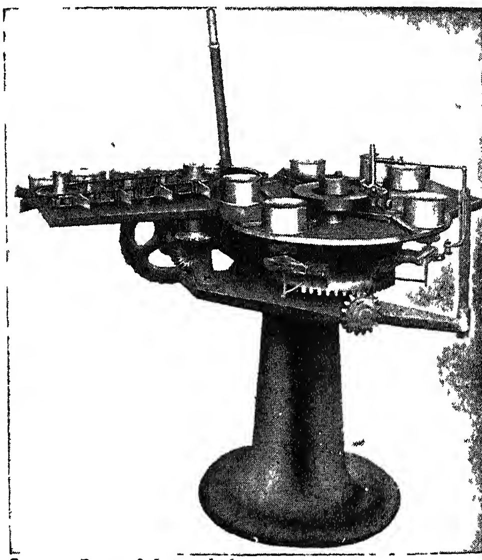
Courtesy Ayars Machine Co

AUTOMATIC BEAN AND PEA CAN FILLER

The machine measures accurately the quantity of beans or peas that goes into each can, and an attachment adds the right proportion of liquor or brine necessary.

For many years canned food was looked upon with suspicion and canning factories were synonymous with cheap labor, untidy conditions and unsanitary surroundings.

Fortunately the canners themselves recognized long ago that the best advertisement they could have was a clean factory, and many make a special point of their sanitary equipment in advertising their goods.



Courtesy Burpee & Letson Ltd

AUTOMATIC WEIGHING MACHINE

Used especially in the salmon canning industry, it separates the cans of full weight from those that are underweight, rejecting the latter, at the rate of 80 a minute.

The laws of most states now define the conditions under which canneries may be operated, and while these are not as yet uniform, the tendency is strongly in that direction with an increasing emphasis on sanitary conditions.

The canning of meat for interstate commerce is carried on under federal supervision and no meat may be used for this purpose that has not passed the inspection of government officials. Similar regulations may be extended to other lines of canned goods though at present such regulation is left largely to state jurisdiction.

The value of canned food put up annually in the United States alone is estimated to be about $800,000,000, and government shipments to the army overseas during the World Wars were colossal

HOW SOUNDS REACH THE EAR

The Characteristics of the Hearing Apparatus of Various Classes of Animals

THE HUMAN RECEIVING SET

IN previous chapters we found that our bodies are provided with receptors or sense organs, which serve as the receiving stations through which pass information of occurrences about us. These organs represent restricted areas of the body surface which have become so refined as to be able to detect very minute changes (stimuli) in the surroundings, such as light, heat, sound, odors and so forth. These stimuli when detected by the receptors are transmitted as impulses over the nerves so as to reach the central nervous system (brain and spinal cord) from which impulses are sent out to the organs of response. As a result these organs, such as muscles, become active in a way that brings the organism into harmony with the forces (stimuli) surrounding it. It will be readily understood that the organism is in a state of constant dodging, thus escaping some stimuli, the unfavorable ones, and coming under the influence of others which are favorable. One sees three important advantages in the receptor system. (1) For each kind of stimulus there is a special receptor, which means that there is present a receptor mechanism for every possible stimulus which is important in the life of the organism. (2) The important sense organs (organs of special senses) are located upon the head of the animal. The animal moves with this end foremost, and as it advances the nature of the new environment is quickly perceived so that the body as a whole may be stimulated to act accordingly—advance, if favorable conditions prevail, or retreat, if that which is unfavorable is encountered (3) The receptors are limited in their extent. If all parts of the surface were equally sensitive to all stimuli, life would be unbearable. For example, if the entire surface were equally as sensitive to light as the retina of the eyes, it would be impossible for the animal to live in the open sunlight

In following up such observations it becomes clear that every organism, including man, is dependent upon sensory information for its general welfare No animal has or can become more intelligent than its receptors will admit, as they are the only portals through which information may pass

As the sense organs have become more refined in the services which they render and more delicate in structure, they have retreated from the surface; that is, they have sunken more deeply into the body mass which has placed them beyond all unnecessary disturbance and injury. The organ of hearing exemplifies the extreme of such a migration. This organ in each individual begins as a mere pit on the surface of the side of the head, and through a process of ingrowth and final complete separation from the surface it comes to lie close to the side of the posterior end of the brain (Fig. 1, a, b, c). Thus the auditory receptor is cut off from the surface in early

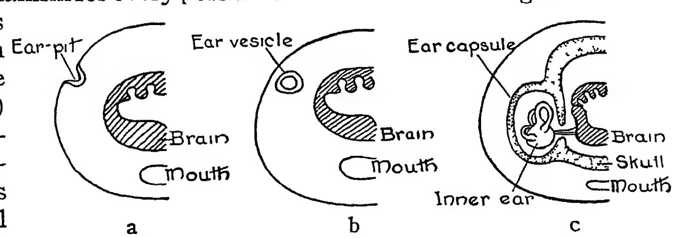


FIG. 1. DIAGRAM ILLUSTRATING THE ORIGIN OF THE EAR AT THE SURFACE, ITS INWARD EXTENSION AND FINAL SEPARATION FROM THE OUTER LAYER

embryonic life. In order to be useful as a receptor it must, however, be able to detect even faint stimuli of the order to which it is adapted. The ear is concerned with the detection of sound waves of a fairly wide range in frequency. Since the ear during its development severs its connection with the surface of the body it is necessary that it be brought secondarily into communication with the surface in order to readily and distinctly pick up sound waves coming from the surrounding medium.

The means of communication between the auditory organ and the surrounding medium constitutes the theme of this chapter. It might also be expressed as the means of transmitting sound to the auditory receptor. The back-boned animals (vertebrates) only will be treated in this connection, for it is possible that below this

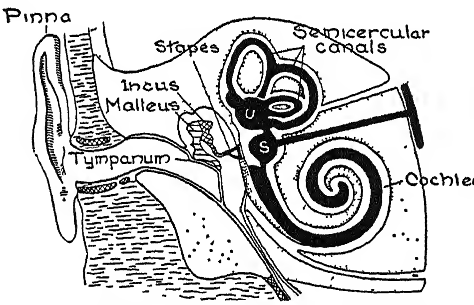


FIG 2. DIAGRAM OF THE PARTS OF THE HUMAN EAR. S., SACCULUS; U., UTRICULUS. AFTER STEMPELL

group the stimulation of organs by sound waves may be different as regards the effects upon the organism.

Since the migration of the ear to its deeper location leaves no structural connection between it and the surface one sees at once that whatever is to serve as the sound-transmitting organs must be appropriated from other and adjacent materials. Of these materials there is only one kind which will serve the purposes of sound transmission in an efficient way, namely, skeletal elements (bone or cartilage). The question of sound-transmitting apparatus is best introduced by a reference to the human ear with the parts of which most persons are somewhat familiar. The human ear-mechanism as a whole is easily divisible into three portions. (1) The pinna or flap, which projects from the surface of the head and deflects sound waves so that they pass into the canal leading more deeply into the mass of the head Across the inner end of this canal there is stretched the tympanic membrane or ear drum (Fig 2). These structures together constitute what is termed the external ear (2) The true auditory sense organ or receptor, that division which originally migrated from the surface to the interior where it becomes fully surrounded by skeletal material (bone or cartilage), the otic (ear) capsule, which fuses with the skull, as shown in Fig. 1c. This division is known as the inner or membranous ear. What is during its earliest stage of development a simple vesicle (Fig. 1a) is pinched off from the surface of the body (Fig. 1b) and gradually becomes a complex sac (Fig. 1c) The original vesicle is constricted at its middle, forming an upper division, the utriculus (Fig 2, U), and a lower division, the sacculus (Fig. 2, S) From the upper division there projects into all three planes of space the semi-circular canals. The lower division gives rise to the elongate, spiral cochlea. The cavities of these parts are all in communication with one another forming a labyrinth and are filled with a liquid, the endolymph. The space between the membranous ear and the surrounding bone is likewise filled with a liquid, the perilymph. In the lining of the membranous labyrinth there are patches of sensory cells which are responsible for the detection of the various stimuli with which the auditory organ is concerned. (3) Between the outer and inner ear there is a space across which a chain of three bones extends (Fig. 2). The outer bone is attached to the tympanum, and is known as the malleus. The next in the series is the incus, and the third is the stapes. These three ear bones constitute the sound-transmitting apparatus of the human ear and together with the space across which they extend form the middle ear. The wall between the middle and inner ear is perforated by the oval window into which the disc of the stapes nicely fits. Vibrations coming from the air impinge upon and are imparted to the tympanum. From here the vibrations are transmitted across the

chain of bones so as finally to affect the liquids of the inner ear, thus ultimately stimulating the sensory parts of the cochlea where the stimulus induces an impulse which passes along the auditory nerve to the brain. The auditory bones are so delicately balanced and adjusted in their relations to one another and other structures, such as the tympanum and inner ear, that they transmit and translate air vibrations to liquid vibrations and in doing so diminish the original air-amplitude of the vibrations to liquid vibrations of minute amplitude and increased intensity.

Since these sound-transmitting bones by their nature are obviously not to be associated in a genetical way with the materials which finally form the inner ear, the problem becomes one of determining their origin. In this connection it may be observed as a generalization that skeletal innovations in Vertebrates are not formed *de novo*. Structures which become useless in one function through a process of remodeling may be brought into the service of other functions. Such instances are numerous in the head-region which has undergone a great many changes related to changes in mode of life. One unfamiliar with the problem might conceive of the auditory bones as having been formed originally in their present position, relations, and functions. In order to get the proper angle from which to view the situation it is necessary to survey the state of the sound-transmitting apparatus in the whole series of Vertebrates from the highest to the lowest forms.

Such a survey shows that all mammals (hairy quadrupeds) are similar to man with regard to numbers, relations, and functions of the bones forming this chain. That is, in all there are the malleus, incus and stapes, constituting the important auditory accessories of the middle ear. Below the mammals one finds a different type of sound-transmitting apparatus. In the birds, reptiles and amphibians there is only a single rod of bone extending between the inner ear and the tympanum. This structure is referred to as the columella (Fig. 3B). In the fishes the external and middle divisions of the ear, as such, are absent which implies that there is an entire absence of any special sound-transmitting organs, leaving the fish-ear in complete isolation as regards direct communication with the outside world (Fig. 3A).

In an attempt to elucidate the nature and origin of the three auditory bones of mammals the procedure may vary according to the whim of the student. The present writer chooses to begin the study with the fishes treating the several groups in their order toward the mammals. At the very outset three observations should be kept clearly in mind: (1) the principle mentioned above relative to the remodelling of useless parts so as to serve in new functions; (2) the nature and relations of parts of the sound-transmitting apparatus in each division of the vertebrates; (3) the value of a careful scrutiny of skeletal ele-

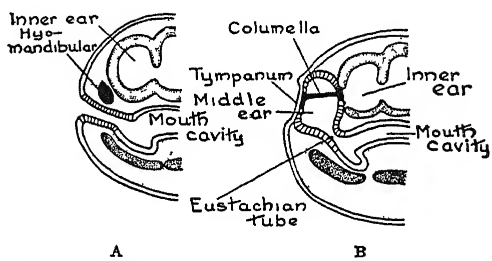


FIG. 3. DIAGRAM OF A SECTION THROUGH THE EAR REGION OF A, A FISH ; B, BIRDS, REPTILES AND FROGS. REDRAWN AFTER STEMPELL

ments adjacent to the ear region, especially those skeletal parts which are concerned with articulating the lower jaw to the cranial portion of the skull. The object of the study may be expressed as that of interpreting the nature of the malleus, incus, and stapes, that is, first as to what they were before they became malleus, incus, and stapes as such, and what was involved in the process of remodelling. An attempt will be made to show that the auditory bones, the articulation of the lower jaw, and intelligence are all associated as parts of the same problem.

A consideration of fishes in this connection opens the age-old controversy of hearing in these lowly vertebrates. An excellent review of the literature bearing upon the question of hearing in fishes has been made including the period from Aristotle's observations down to 1918. The author

of the review concluded that fishes hear, since they appear to respond to sound stimulation. Many difficulties are encountered when one attempts to analyze the sense of hearing in fishes. Sound waves might stimulate the animal through the touch organs or pass directly from the dense liquid medium in which they live through the substance of the head so as to affect the inner ear or through a series of refined organs scattered along the sides of the body and known as the lateral-line organs. These respond to waves much lower in frequency than the lowest which the human ear detects. It is in essence a pressure sense, and as a sense it stands between hearing and the grosser sense of

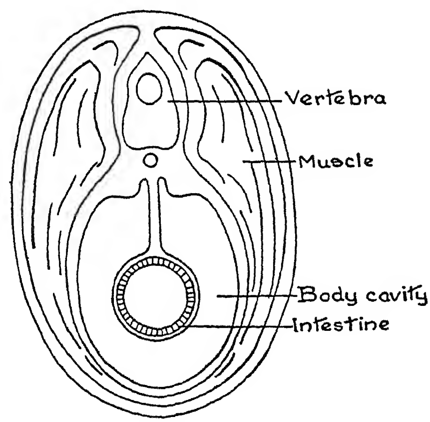


FIG. 4. DIAGRAM OF A TRANSECTION OF THE FISH BODY SHOWING THAT THE GREATER WEIGHT IS ABOVE THE CENTER OF THE BODY MASS

touch. After a careful consideration of the review mentioned above it is just as satisfactory to believe that fishes do not hear, concluding that vibrations whether in the nature of noise or tones affect the organs of static sense. Although not conclusive, in certain peculiar cases the response of the fish to sound stimuli is the same as that to static stimuli. The importance of the inner ear of fishes in maintaining balance must be adequately estimated. The fish body is suspended in water free to turn in any direction, especially to roll or to assume a position with two ends out of level. The rolling possibilities are of first importance to the fish. A transection of a fish body (Fig. 4) reveals the situation. It is readily seen that the greater weight of the body is above the center of the body-mass. That is, the fish is "top heavy". Being suspended in water the back would roll to the under side, bringing the belly toward the surface. This is exactly what happens to the body of the dead fish. During life the inner ear detects any such change in position, communicates with the brain, and the properly directed impulse is transmitted to the paired fins which execute movements of such a kind as will maintain the back in its proper relative position. It would seem logical to suppose that the inner ear is thus constantly occupied and that its balancing function is therefore the dominant one. It would also seem reasonable to suppose that the sensory equipment of the inner ear is mainly adapted to such a function which is a primal one. Furthermore, there is no reason for believing that sound waves do more than stimulate the inner ear in the way of a general disturbance similar to that produced by a shift in balance. A response to sound waves does not indicate that fishes *hear*.

In whatever manner one may interpret hearing in fishes the fact remains that no special sound-transmitting organs are present. Furthermore, it seems quite likely that sound waves of a high frequency are of little value in the life of the fish. A true conception of hearing in fishes or any other group below man cannot be formed until there is discovered some means of bringing within the limits of understanding that which is beyond the experience of man.

Advancing to the amphibia (salamanders, frogs, toads, Figs. 5–7) one finds that a sound-transmitting apparatus is present although not uniform in its relations throughout this group of animals. Such variations as exist can be correlated with the mode of life.

The two groups of amphibians with which we will need to deal are readily distinguished, and one group at least is familiar to all. The frogs and toads are to be ranked as terrestrial forms when the adult state is reached, and distinguished from the other group by the absence of a tail and the presence of elongate hind legs

which engender the leaping mode of progression (Fig. 5). The other group is typified by the common salamanders (Fig. 6), in which there is only a slight difference in the length of arms and legs, and in which the tail is present throughout life This group will be referred to as the salamanders.

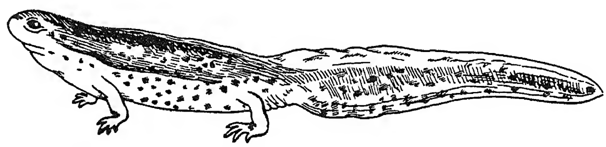


FIG. 6. ADULT SALAMANDER. AFTER GAGE

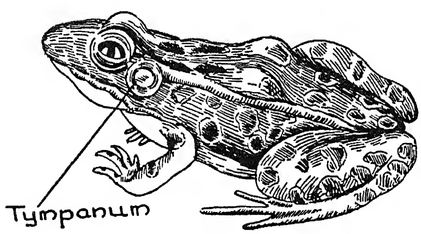


FIG. 5. FROG

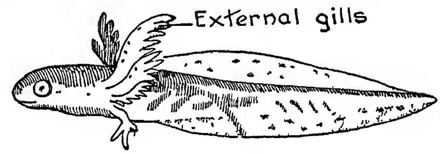


FIG. 7. LARVAL SALAMANDER. AFTER SHIPLEY AND McBRIDE'S "ELEMENTARY TEXTBOOK OF ZOOLOGY," BY PERMISSION OF THE MACMILLAN COMPANY, PUBLISHERS

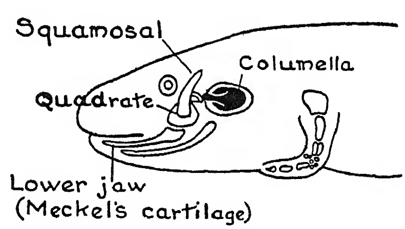


FIG. 8. SCHEMATIC REPRESENTATION OF THE POSSIBILITIES OF DISTURBANCES PASSING OVER THE JAWS AND COLUMELLA SO AS TO AFFECT THE INNER EAR IN LARVAL SALAMANDERS

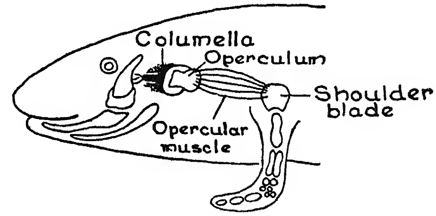


FIG. 9. SCHEMATIC REPRESENTATION OF THE POSSIBILITIES OF DISTURBANCES PASSING THROUGH THE ARM AND OPERCULUM, THUS REACHING THE INNER EAR IN ADULT SALAMANDERS

In the life cycle of the amphibia there is a period between "hatching" and the adult state during which the animal is aquatic, and among its adaptations to such an existence are a cresc or fin upon the tail which serves as the organ of propulsion, and tufts of fringed outgrowths in the neck region called external gills, which as the name implies serve the function of respiration in taking the air which is dissolved in the surrounding water. This is the larval period. The general appearance of a larval salamander is shown in Figure 7. In advancing from fishes, where no sound-transmitting apparatus is present, to the amphibia one finds the change in this respect abrupt; that is, the single rod or columella extending between the inner ear and some other structure shows no transitional stages in any living forms. The service this rod performs for these animals is clearly correlated with their mode of life. In the salamanders no tympanum or ear drum is present (compare Figures 5 and 6). The columellar rod extends from the inner ear, where its relations are established through a circular plate fitting into the oval window. At its distal (outer) end the columella is connected with a series of bones supporting the lower jaw (Fig. 8). The relation of the distal end of the columella to the jaw mechanism indicates clearly that the function of this rod in salamanders is not that of transmitting sound vibrations from the surrounding medium, although coarser disturbances might readily pass over it. It is to be noted that during the larval period, when the animal is not swimming, it rests upon some object in the water or directly upon the bottom, with which the under surface of the head and trunk are more or less in contact. This suggests that the inner ear is not stimulated by sound vibrations coming by way of the

columella, but rather by jars and jolts transmitted from the substratum through the jaws and thence over the columella to the inner ear

It is conceivable that such a disturbance could produce the same effects upon the sensory structures of the inner ear as a shifting of balance in the body. The interpretation should be then, that no sense of hearing is aroused but rather a sense organ has been stimulated, the effects upon the organism being the same whether the stimulus be jars, body posture or sound wave. So far as structural, or experimental information can be drawn upon as contributing toward an interpretation one is unable to recognize hearing as a function of the inner ear of these organisms any more than in fishes. It appears rather that the detection of disturbances in the substratum upon which the animal rests becomes a function of the inner ear. Further evidence of such conclusions is found in the changes in the sound-transmitting apparatus which accompany the change from the larval aquatic life to the adult terrestrial. During this metamorphosis the tail-crest or fin and the external gills disappear. The animals leave the water to take up a terrestrial existence, drawing upon air directly rather than appropriating that which is dissolved in water, as do the larvæ. Upon the assumption of terrestrial life the head is more or less elevated from the substratum through the support of this part of the body upon the arms, which have by this time assumed a locomotor rôle. Disturbances can no longer be transmitted through the jaws so as to reach the ear by way of the columella. At such a time the columella is found to fuse with the bone of the ear capsule, but behind the columella (Fig. 9) a new circular plate is formed from the material of the ear capsule itself.

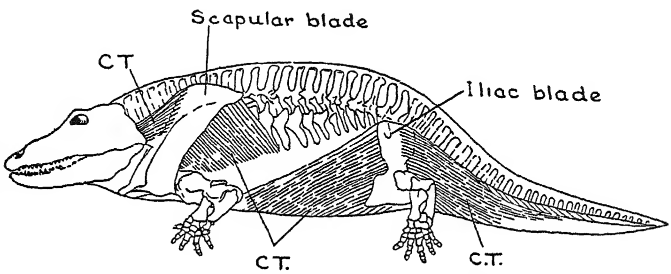


FIG. 10. DIAGRAM OF A PRIMITIVE QUADRUPED TO SHOW THE SUSPENSION-BRIDGE PLAN OF ARCHITECTURE ACCORDING TO WHICH THE BODY IS BUILT. C T, CANTILEVER TRESTLE-WORK AFTER GREGORY

This plate is called the operculum (meaning cover or lid). It, through the appropriation of fibers of near-by muscles, becomes directly connected with the shoulder-blade, so that thereafter disturbances in the substratum may be transmitted through the arm, shoulder-blade and opercular muscle, thus reaching the operculum, which in its turn transmits the disturbance to the liquids of the inner ear From these structural relations and changes which accompany changes in the mode of life one concludes that salamanders do not hear as we use the term in its application to higher animals, but rather is enabled, through the inner ear as a receptor, to detect disturbances in the substratum upon which the animal rests Such a function would make the organism aware of approaching objects or dangerous occurrences in time for it to escape.

In the case of the frogs, a tympanum is a conspicuous feature on the side of the head (Fig. 5). Knowing its nature and function in higher animals the presence of the tympanum in frogs suggests that these animals are endowed with an inner-ear sense superior to that of salamanders and fishes.

The proper dissection of the tympanic and middle-ear region reveals a single rod extending from the inner surface of the tympanum to the oval window in the ear capsule (Fig. 3B). This rod is the columella which has retained its relations with the oval window but whose outer end has shifted in position so as to form a contact with the inner surface of the tympanum rather than with the jaw mechanism, as in the salamanders.

In connection with ear functions it is profitable to recall that the amphibians are the nearest living relatives of the pioneers in quadrupedal locomotion upon land. Dr. W. K. Gregory of the American Mu-

seum of Natural History has written of this first attempt at terrestrial locomotion in a very clear manner by pointing out the similarity of an animal body supported on four limbs to a suspension bridge. "The primitive tetrapod was essentially a creature in which, as seen from the side (Fig. 10), the scapular blade of the shoulder girdle constituted the first tower of a suspension bridge, while the iliac blade of the pelvic girdle formed the second tower. The pathway of the bridge would be represented by the back-bone, while the cantilever trestle-work (C. T.) supporting the pathway would be represented by the ribs and by such muscular springs as the serratus muscles of the pectoral and the oblique abdominal muscles of the pelvic girdle". While this provides the body with mechanical efficiency, it must be noted that the towers (the limbs with their girdles) of the "animal-bridge" are movable, thus introducing instability to the whole, which is compensated by the primal balancing function of the inner ear.

After reviewing the situation as regards the sound-transmitting apparatus one recognizes that the ear in these low terrestrial vertebrates while initiating the function of audition endures as an organ mainly in the service of balance. While the writer believes that hearing does not obtain in salamanders it appears that in the frog-group a crude sort of audition exists. This is indicated by the presence and relations of the tympanum and columella, by observation and experiment, and by the fact that there is in the membranous labyrinth what appears to be the primordium of a cochlea which in mammals and man (Fig. 2) is the important organ of auditory reception.

In whatever way one may interpret the auditory situation in the amphibia the sound-transmitting apparatus itself is of value by way of offering some explanation of the nature of this apparatus in the higher animals.

If one were to observe the side of the skull of a primitive shark there would be found two elements constituting the framework of the jaws, the upper element articulating with the lower, which is called Meckel's cartilage (Fig. 11). Behind the articulation there is found an element supporting the jaws near their articulation, as is shown by ligaments extending toward the jaws This element is termed the hyomandibular In the amphibia this element as such is not to be found. The lower jaw at its posterior

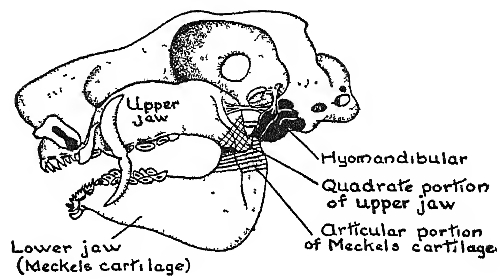


FIG. 11. DRAWING OF LEFT SIDE OF THE SKULL OF A SHARK. AFTER STEMPELL

end is articulated with an element called the quadrate (Fig. 12), which in its turn is articulated with the columella, thus establishing a means of communication between the inner ear and lower jaw, as already pointed out. A study of the development of the parts already mentioned and their relations to one another shows that the columella is a transformed hyomandibular element which as a columella is performing a new function but bears the same relation to the jaw mechanism and ear capsule that it bore in the sharks, the difference being that the upper jaw of the shark (Fig. 11)

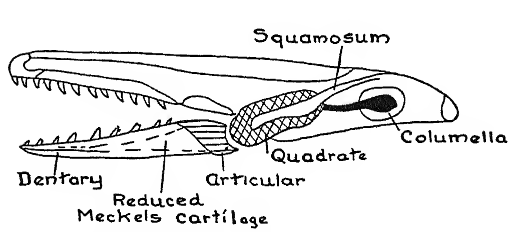


FIG. 12. SCHEMA OF SALAMANDER SKULL

has been reduced to a small portion representing the original articulating portion or quadrate which retains its original shark-like relations to the lower jaw and hyomandibular (columella). The posterior end of Meckel's cartilage has ossified as the articular bone, the rest having been reduced and replaced by a new element,

the dentary bone, which constitutes the major part of the lower jaw.

Written in summary fashion the situation is this: The Meckel's cartilage constituting the lower jaw of the shark becomes merely the articular bone of the lower jaw in the amphibia; the upper jaw of the

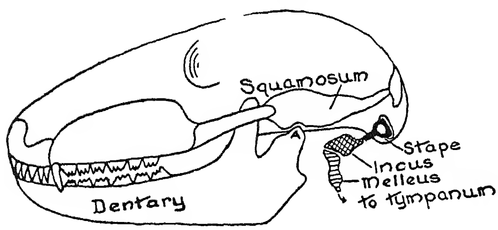


FIG. 13. SCHEMA OF MAMMALIAN SKULL AND AUDITORY BONES

A, articulation of the dentary bone of the lower jaw with the squamosum.

shark becomes the quadrate of the amphibia; the hyomandibular of the shark becomes the columella. But, although much modified and somewhat changed in function, these bones in the amphibian are in the same relative positions as in the sharks. Thus, without creating any new parts, the amphibian ear came into direct communication with the outside by remodelling, as it were, parts already well established in this region. In the frog the columella shifts its outer end from the quadrate to the inner surface of the tympanum.

A survey of reptiles and birds reveals the fact that a single piece only connects the inner ear with the tympanum, as in the frog (Fig. 3B) and the study of development has justified the conclusion that this single rod in reptiles and birds represents the columella of amphibia with certain modifications chiefly in the way of additions. It is to be emphasized in this connection that the jaw mechanism in reptiles and birds is found to be essentially that of the amphibians, namely, that the lower jaw articulates with the quadrate and this element in its turn becomes attached to the side of the cranium so that full support is given to the mechanism as a whole. It is further to be emphasized that in the shark the sequence of elements, jaw to quadrate, to hyomandibular is the same as in amphibia, reptiles and birds, that is, articular bone to quadrate, to columella.

In the mammals another abrupt change is encountered. There is met for the first time in the vertebrate series the chain of three bones as the sound-transmitting apparatus referred to above as the malleus, incus and stapes. It is also to be observed that the lower jaw articulates directly with a cranial element called the squamosum (Fig. 13). It is important to note that, as such, the quadrate and Meckel's cartilage (the lower jaw of the shark) are absent. Here again comparative and developmental studies show the way to an interpretation of these differences. In reptiles the posterior end of Meckel's cartilage which forms the articulation with the quadrate ossifies as a distinct bone, the articular (Fig. 14). The rest of Meckel's cartilage in these animals either disappears or is much reduced, and about that region in front of the articular a new bone, the dentary, is formed independently of the Meckel's cartilage. As in the frog, the outer end of the columella loses its ancient relations with the quadrate and becomes attached to the inner surface of the tympanum.

Among living animals the transition from the reptilian to the mammalian state as regards ear and jaw structures is marked by abruptness. In the reptiles only the columella as a sound-transmitting apparatus is present, and both quadrate and articular bones are present forming the articulating mechanism of the lower jaw. In mammals both quadrate and articular elements appear to be absent, but a chain of three bones forms the sound-transmitting apparatus. It is also a noteworthy fact that the mammalian lower jaw articulates with the squamosal through an upward projection from the posterior region of the dentary (Fig. 13A).

The reptilian and mammalian structures can be harmonized by a brief statement of the changes which took place in the distant past. In some ancient reptile-like form an upward projection of the dentary bone began (Fig. 14A) while the articular and quadrate were still functioning as the articulating bones for the lower jaw. When this projection reached the squamosal so as to form an articulation (Fig. 13A) it

scooped this function from the articular and quadrate, both of which were left without any duties whatever.

When emancipated from jaw-functions the articular and quadrate bones nevertheless retained the relations which had existed since the shark stage. The articular became attached to the tympanum which formed in this region thus effecting a chain of three bones connecting the inner ear with the outside world through the agency of the tympanum or ear drum. That is, the articular became the malleus, the quadrate the incus, and the columella the stapes

The appearance of a chain of three ear bones in mammals is coincident with the greatest advance in acuteness of hearing and intelligence in vertebrates. There is every reason for believing that the vibrations finally transmitted to the inner ear by a chain of delicately balanced bones differs in important ways as a stimulus from vibrations transmitted across a solid rod, and it is unquestionably this change in the transmitting apparatus which has contributed to a more acute type of hearing.

It is among the mammals that intelligence has experienced its greatest advance Since intelligence is dependent upon sense experience it is evident enough that the ear with its more perfect sound-transmitting apparatus has contributed toward advanced intelligence in proportion to its own advancement.

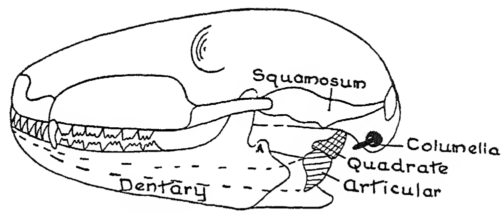
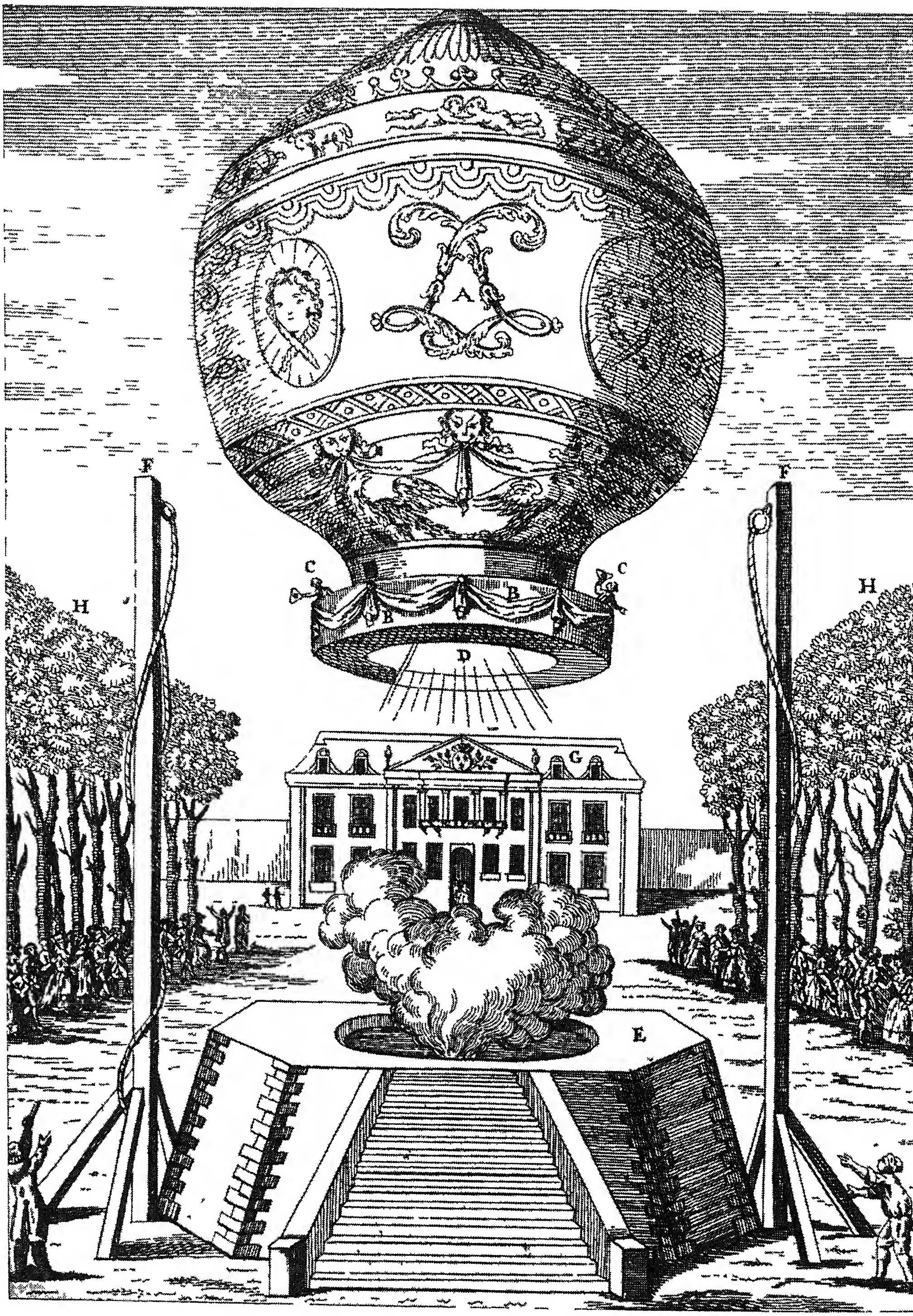


FIG. 14. SCHEMA OF ANCIENT REPTILIAN SKULL

The mammals waited a long time, however, for the release of the proper elements from the grosser functions of jaw movements to be enlisted in the more refined service of transmitting sound waves.

In following out this chain of events in both its structural and functional aspects one is led finally to view this shift in the articulation of the lower jaw as directly related to intelligence.

A NOTABLE "FIRST" IN AVIATION HISTORY



Man's first flight, which took place in Paris on November 21, 1783 Pilâtre de Rozier and the Marquis d'Arland rose from the ground in a Montgolfier balloon, which had been inflated with hot air

THE CONQUEST OF THE AIR

The Inspiring Saga of Airships and Airplanes

MANY hundreds of years ago the storytellers of the East kept their listeners spellbound with their tales of a wonderful magic carpet which carried the princes of Bagdad through the air. To-day without benefit of magic man has conquered the skies. He can rise miles into the upper air; he can fly over the highest mountains, the most forbidding deserts and the broadest oceans; he is even seriously thinking of a journey to the moon.

Some of the aircraft in which man has achieved flight remain aloft because they are lighter than air. Others are heavier than air, but can outdo the birds in flight because they are driven by power plants or because they are carried up into the air by powerful air currents. We shall begin our story with lighter-than-air craft—balloons and dirigibles—because in them man first began to fly.

LIGHTER-THAN-AIR FLIGHT

The principle of lighter-than-air flight is simple enough. If any object is lighter in weight than the volume of air that it displaces, the force of buoyancy will lift it upward so that it will float in the atmosphere. The problem is to find a substance that is lighter than air.

The Chinese solved the problem many centuries ago. They learned that heated air weighs less than ordinary air; by inflating hollow paper dragons with hot air they were able to send the toys aloft. The Chinese did not take these flying dragons very seriously; of course they had no idea that one day a balloon based on the same principle would make it possible for man to fly.

The honor of this achievement was reserved for Joseph-Michel and Jacques-Etienne Montgolfier, two brothers who lived in France in the eighteenth century. They inflated paper balloons with hot air produced by straw fires, and watched them rise in the air. Later they used globes made of silk and suspended cages from them; in these craft they sent chickens, ducks and sheep aloft. Finally, on November 21, 1783, two young Frenchmen, Pilâtre de Rozier and the Marquis d'Arland ascended in a Montgolfier balloon, which was kept fastened to the ground by a long rope. They were the first men ever to fly in a lighter-than-air craft, or in any craft for that matter.

The practice of inflating balloons with hot air was soon abandoned. Men came to realize that the recently discovered gas hydrogen, even when cold, is much lighter than air. In 1783 a French physicist, J. A. C. Charles, filled a silk balloon with hydrogen and sent it aloft without passengers; somewhat later he made several flights himself in a hydrogen-filled craft. More balloon flights followed; soon the big gas bags were being flown in many lands. They were all free balloons: that is, they could not be steered but flew wherever the winds carried them.

Military men began to be interested in the possibilities of these lighter-than-air craft. They were used for scouting purposes by the French in the last years of the eighteenth century. During the American Civil War (1861-1865) Professor T. S. Lowe organized a balloon observation corps for the Union side. His balloons were of the captive type; they were held by cables and were equipped with telegraphic equipment so that they could send artillery-fire observations back to the ground. The French made good use of balloons during the siege of Paris in the Franco-Prussian War (1870-1871). These craft carried microphotographs (greatly reduced photographs) of mail out of the city; replies went to Paris by carrier pigeon. Some 20,000

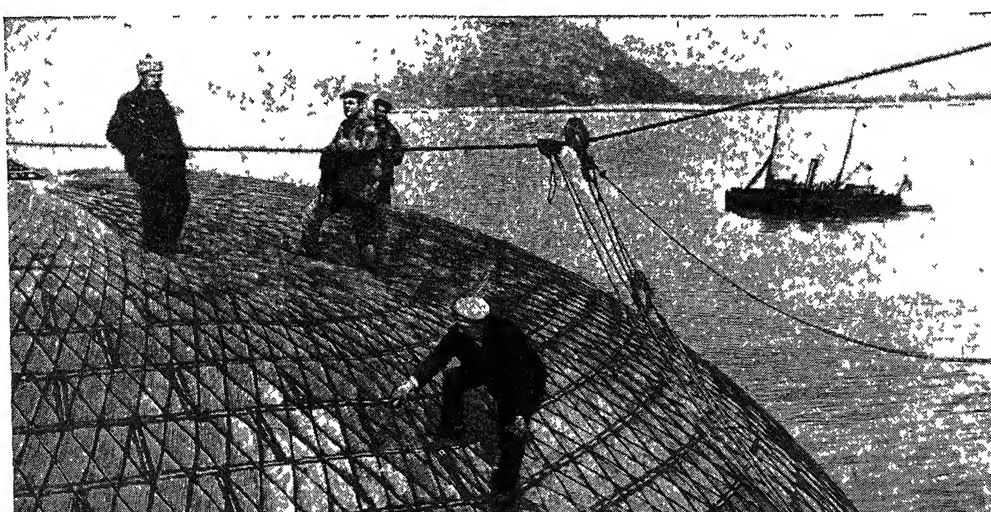
pounds of mail were carried in this way in the period from September 23, 1870, to January 28, 1871.

In 1897 the Swedish engineer Salomon August Andrée launched upon perhaps the most daring lighter-than-air flight ever attempted. With two companions he took off in a balloon from Spitsbergen in an attempt to float across the North Pole. For years there was no further word of the three adventurers. At last, in 1930, the bodies of the explorers were found on White Island, together with much of their equipment, including some undeveloped negatives of photographs taken by Andrée. The three unfortunates had been forced down on an ice floe and had managed to make their way to White Island, where they had perished of exposure and cold.

The disastrous result of the Andrée expedition clearly showed the haphazard nature of flying in a free balloon. From the earliest days of lighter-than-air flight, men had sought to develop a dirigible—a balloon that could be fully controlled while in the air. Some of the early students of aeronautics thought that this could be done by means of sails, oars and rudders; of course such devices as these proved futile.

In 1851, a Frenchman, Henri Giffard, fitted a big balloon with a 3-horse-power steam engine which drove a propeller. Giffard's dirigible really flew, attaining a height of 5,000 feet; it answered its controls quite well. But it was altogether too slow; on a windless day its top speed was 6 miles an hour—only slightly above walking speed. The fact was that the 350-pound engine was much too heavy, considering the slight amount of power it produced. Following Giffard, other experimenters developed dirigibles that could stay aloft and that could be navigated after a fashion. One of the most interesting of these craft was an airship designed in 1885 by the Frenchmen Charles Renard and A. C. Krebs; it was driven by a storage battery and once managed to travel at the breath-taking speed of 13 miles an hour!

It was not until lightweight gasoline engines were developed that really successful dirigibles were constructed. Alberto Santos-Dumont, a wealthy Brazilian living in Paris, built fourteen dirigibles, powered by gasoline engines, between the years 1898 and 1908. With one of these airships he won a prize of $20,000 for rising in the air at a place a few miles away from the Eiffel Tower, circling the tower and then returning to the starting point, all within half an hour. Santos-Dumont's dirigibles were quite primitive; they consisted of sausage-shaped balloons under which light keels, carrying the engines and crew, were slung.

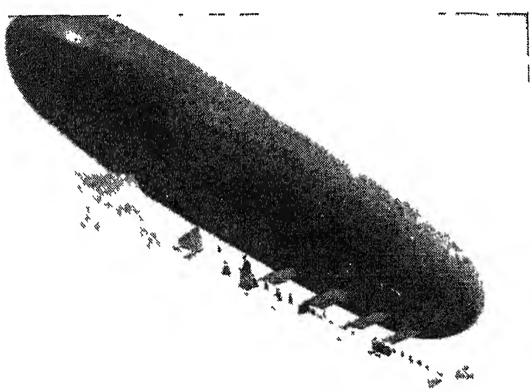


The Bettmann Archive

Inspecting Dr. Andrée's balloon at the start of his ill-fated attempt to float across the North Pole.

In the meantime, Count Ferdinand von Zeppelin, a retired German army officer, had started to build rigid dirigibles. He constructed a framework of aluminum for his airships; he divided the interior of the craft into compartments, which were filled with small gas bags, called ballonets (little balloons). Two cars, one for the engines and the other for the crew, were suspended from the framework. The Count's dirigibles, called zeppelins after their inventor, proved to be quite successful; in the years before World War I thousands of passengers were carried in them.

Free balloons and dirigibles saw service in World War I (1914-1918). Both sides used captive balloons to direct artillery fire. The zeppelins served for scouting purposes;



Wide World

The dirigible built by Santos-Dumont in 1903.

they were also employed to bomb areas behind the front and they inflicted considerable damage. In time, however, they were driven from the skies by heavier-than-air craft, which were speedier and more maneuverable.

The English and, later, the Americans used nonrigid dirigibles for antisubmarine patrol in coastal waters. The English had given the name of "limp airships" to all such craft; the particular model used for coastal patrol in World War I was known as Type B-limp. This gave rise to the word "blimp," which is still used for a nonrigid dirigible.

After the war the most important use of free balloons was in scientific research. The stratosphere—the upper air—was explored by small crewless hydrogen-filled balloons. Each of these contained a radiosonde—a collection of miniature scientific instruments. These automatically operated a tiny radio transmitter, which continuously sent reports to ground stations. When the atmospheric pressure at great heights became too low, the internal pressure of the hydrogen gas within the balloon caused it to break; the radiosonde then descended to earth by parachute. Radiosonde-carrying balloons are still widely used by weathermen in different parts of the world.

Auguste Piccard makes a flight to the stratosphere

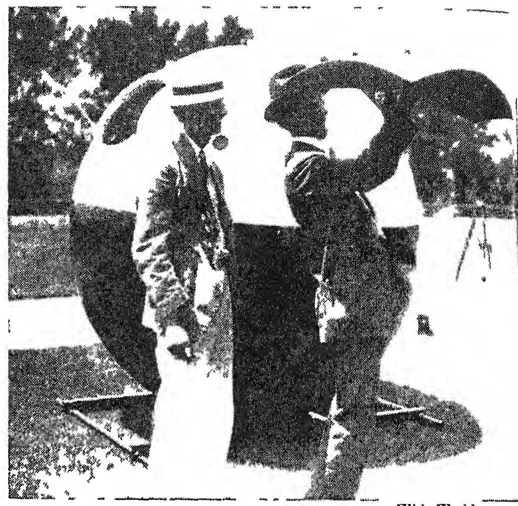
On May 27, 1931, a Swiss physicist, Auguste Piccard, and an assistant made an epoch-making flight to the stratosphere, using a free balloon, from which a big metal ball was suspended. The balloon was only partially filled on the ground in order to allow for the expansion of the gas as it rose. Piccard and his assistant took their places in the metal ball, which was equipped with a great deal of special apparatus. The balloon rose majestically to a height of 51,775 feet—9⅘ miles—in the air. The occupants brought back with them much valuable information about solar radiations and cosmic rays. Other flights to the stratosphere followed. In one of these, two American army officers, Captains Albert Stevens and Orvil Anderson, reached the altitude of 72,395 feet—the highest that has ever been attained by man.

Rigid airships seemed destined to play an important part in aviation after World War I. The remaining zeppelins of the Germans had been distributed among the victorious Allies, many of whom had already built or were building airships of their own. A few of these craft had impressive records. In 1919, the British dirigible R-34 flew from England to the United States and also made the return trip. The Los Angeles, built by Germany for the United States, was operated by the United States Navy until 1932, when it was decommissioned after having covered 140,000 miles in 250

flights without a mishap. In 1929 the German commercial airship Graf Zeppelin flew around the world in a little over 21 days. Later it was used in regular passenger service between Germany and South America. It crossed the Atlantic more than 125 times, carrying 13,000 passengers in all.

On the whole, however, misfortune seemed to dog the big gas bags. There was a series of terrible disasters; one after another of these leviathans of the air caught fire in mid-air, or crashed to the ground or fell into the sea. The last of these disasters happened in 1937, when the German ship Hindenburg burst into flame as she was nosing up to her mooring mast at Lakehurst, New Jersey, after a flight from Germany; she was destroyed, with a loss of thirty-six lives.

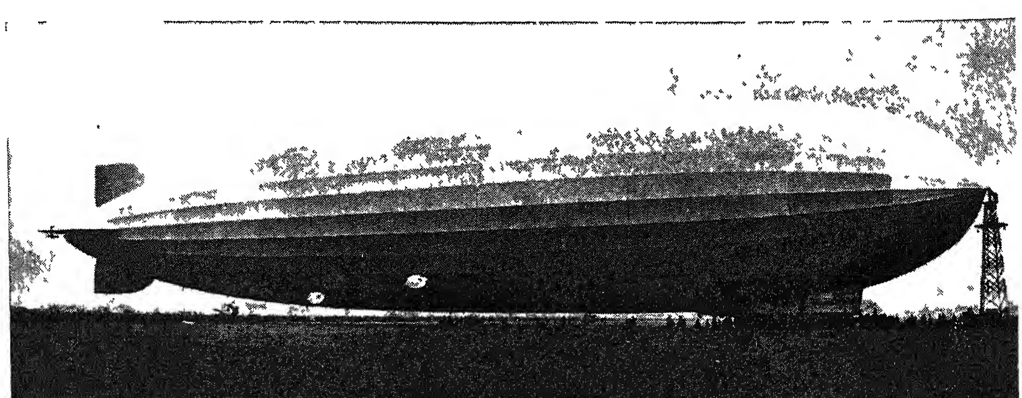
The rigid airship was not the only type of dirigible used in the period between the two world wars. The semirigid type, supplied with a keel and a few ribs, also saw a certain amount of service. One of the most famous semirigid airships was the Italian-built Norge, in which Roald Amundsen, Lincoln Ellsworth and Umberto Nobile flew across the North Pole in 1926. Nobile attempted to repeat the flight in the semirigid Italia in 1928, but the ship crashed on the ice. Nobile himself was rescued, but several of his men lost their lives. Nonrigid airships also saw considerable service. The United States built a fleet of such ships, which were used chiefly for passenger-carrying and advertising purposes.



Wide World

Auguste Piccard (right) and his brother Jean standing beside the gondola of a stratosphere balloon.

Another development of the period between World Wars I and II was the use of helium to inflate lighter-than-air craft. For years all free balloons and airships had been inflated with hydrogen or with illuminating gas, which contains a large proportion of hydrogen. Hydrogen is the lightest of all gases but unfortunately it catches fire easily and therefore it is very dangerous. Helium is much more satisfactory for lighter-than-air craft; though it is heavier than hydrogen, it is much lighter than air and, what is particularly important, it cannot catch fire. This gas is found in the sun, in the atmosphere (in very small quantities) and in natural gas derived from wells in



Passengers preparing to board the famous dirigible Graf Zeppelin, about to begin a routine flight.

Texas. In the 1920's a method was developed for extracting helium at reasonable cost from these Texas wells. From that time American airships were inflated with helium. The United States has a monopoly on this light and nonflammable gas.

Lighter-than-air craft did not figure prominently in World War II (1939-1945). The British flew clusters of captive balloons, called balloon barrages, over their cities to keep attacking planes from descending close to their targets. Individual balloons were fastened to ships to discourage the enemy's dive bombers. As in World War I, nonrigid warships saw service in antisubmarine patrol duty. The Japanese sent aloft free balloons made of oiled paper and carrying explosives, in the hope that aerial currents would carry them to the west coast of the United States. A few did reach the coast, but only one did any damage. It landed on a hillside and attracted the attention of some curious picnickers; they unwittingly set off the explosives and were killed.

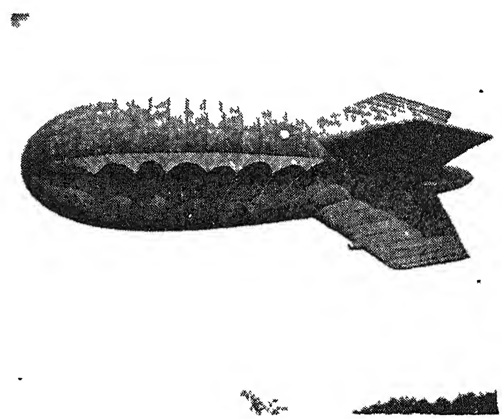
Such uses of lighter-than-air craft did not loom large in the general pattern of air warfare in World War II. Throughout the war the heavier-than-air plane dominated the skies.

The future of lighter-than-air craft is in doubt. Blimps will continue to be used, perhaps, for advertising purposes and, in warfare, for antisubmarine patrol. Bigger craft may serve for special military missions. Free balloons will continue to play an important part for some time to come in weather research and in the study of the upper air. But as far as we can see, heavier-than-air craft are destined to remain supreme in the field of aviation.

HEAVIER-THAN-AIR FLIGHT

Some of the earliest pioneers in heavier-than-air flight tried to imitate those marvelous little aviators, the birds. In the thirteenth century an English monk, Roger Bacon, proposed that men should use flapping wings, like those of birds, to achieve flight. Several centuries later the great Italian artist-scientist, Leonardo da Vinci, drew up plans for an ornithopter, or bird machine, following the suggestion of Bacon; the flapping wings of the craft were to be operated by hand. Leonardo never developed a successful ornithopter, nor did anybody else.

The Englishman Sir George Cayley tried a different approach, and as a result became the father of heavier-than-air flight. He had noticed that birds could remain aloft for long periods of time without moving their wings. He proceeded to fashion a number of gliders with wings shaped like those of birds. Men running against the wind launched the craft, which made a number of short flights. Cayley never succeeded in building a man-carrying glider. The first to do so was a Frenchman, Jean-

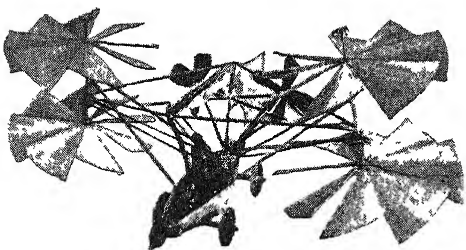


Goodyear

Typical barrage balloon used in World War II

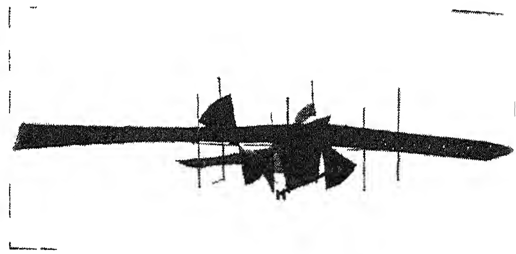
Marie Le Bris, who made a short flight in 1855 in a glider that was built on the model of the graceful albatross.

Later in the century other enterprising pioneers experimented with gliders. Foremost among them was Otto Lilienthal, a German inventor. First he made a thoroughgoing study of the theory of heavier-than-air flight; then in 1891 he constructed a curious kind of glider which outdid all its predecessors. It combined bat-like wings with a strap arrangement which permitted Lilienthal to hang from the center of the machine while it was in flight. He controlled it by swinging his legs and his trunk this way and that. Lilienthal was flying one of his "hang gliders" in 1896 when he



National Air Museum

A helicopter model designed by Sir George Cayley



The Science Museum, London

The steam-powered monoplane of W. S. Henson.

lost his balance, crashed to the ground and was killed.

His work was carried on by Percy S. Pilcher in England and Octave Chanute in the United States. Many improvements were made in the glider. Chanute developed a machine with wings that could be twisted while in flight; he added a vertical tail which stabilized the glider and kept it flying in a straight line.

Orville and Wilbur Wright, two bicycle builders of Dayton, Ohio, began experimenting with gliders at the turn of the century. They discarded many of the ideas of their predecessors. For one thing the trailing or rear edges of the wings were made flexible and were worked by ropes in order to control the lateral, or side-to-side, position. The gliders of the Wright brothers proved to be very successful; in one of them they made more than a thousand flights during September and October 1902.

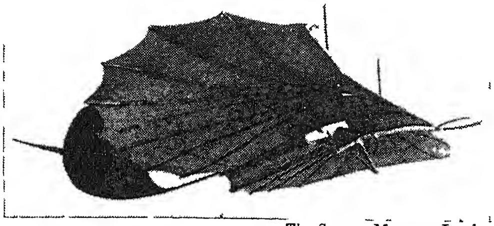
The brothers now felt that the time was ripe for powered heavier-than-air flight. The idea was by no means new. In 1842 William S. Henson of England had constructed a full-scale monoplane, which was to be driven by a thirty-five-horse-power steam engine. It was a total failure. His partner, John Stringfellow, built a small-scale model steam-driven plane, which he managed to get aloft in 1848. However, these early experiments were doomed to failure, because the steam engines of those days were much too heavy to be used in planes.

When the Wrights began to work on a powered airplane, the gasoline engine had already been developed. But the brothers found that no existing motor was light enough for their flimsy craft and at the same time powerful enough to propel it through the air. They decided, therefore, to develop an engine of their own. They built a lightweight twelve-horse-power engine and by December 1903 they were ready for their first flight in a powered airplane. But a rival airman almost anticipated them.

In the 1890's Professor Samuel P. Langley, an eminent American astronomer, had begun to experiment with small model planes powered by rubber bands and, later, with larger models driven by steam engines. At last Langley decided to construct a full-scaled powered plane. His assistant, John Manley, built a five-cylinder gasoline engine for the plane, which was called an aerodrome, and on December 8, 1903, it was ready for flight.

Langley and Manley got into the aerodrome, which was then catapulted from the roof of a houseboat in the Potomac River. But the launching gear was defective and the craft plunged ingloriously into the Potomac. The press ridiculed Langley's ill-fated attempt to fly and the broken-hearted inventor abandoned his work. As a matter of fact his plane was quite airworthy. Years later a well-known aviator, Glenn Curtiss, made a few changes in its structure and flew it successfully.

On December 13, 1903, the Wrights were ready for their own attempt at powered flight. It took place on the beach near Kitty Hawk, North Carolina. A single rail was laid upon an incline at the beach. A truck was put in place upon the rail at the top of the incline; then the plane, which was provided with skids, was balanced on the truck. Orville Wright got into the machine and lay prone on the lower wing. The motor was started and warmed up



The Science Museum, London

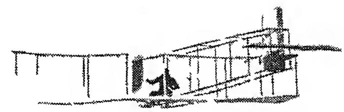
Otto Lilienthal's glider, with its bat-like wings.

while assistants held the plane in position; then the signal was given and the craft was released. The truck slid down the rail; the plane rose into the air, leaving the truck behind. It flew for a distance of 120 feet, remaining aloft for twelve seconds, and then landed on its skids. Later that day, the brothers, taking turns at the controls, made three more "hops," or short flights.

The plane in which the Wrights had achieved flight was a far cry from the mighty stratoliner or heavy bomber of to-day. It was a biplane (two-winged plane); its wings were made of fabric and were held together by struts and wires. The engine was set on the lower wing, to the right of the pilot; the propellers were at the back of the plane and pushed it through the air.

It was not until the Wright brothers had made a number of flights in England that the public at large began to show genuine interest in heavier-than-air flying machines. The Wrights constantly improved their plane, until by 1905 it could remain aloft for more than half an hour and cover some 25 miles. Other pioneers developed planes of their own. Some of these were biplanes; others were triplanes, with three wings; still others were monoplanes, with but a single wing. One of the most successful of these early flying machines was a monoplane built by Louis Blériot, a Frenchman. In this frail craft he crossed the English channel in 1909, covering 31 miles in 37 minutes—a remarkable feat for that time.

When World War I broke out in 1914, airplanes were still a novelty; little had been done to put them to practical use. A few military services had employed them for scouting purposes. They had carried mail in the United States and in England;



One of the early gliders of the Wright brothers in flight. It could remain aloft for several minutes.

but no regular mail service had been established. At the outset of the war the total number of planes in the world was still small.

The airplane really came of age in the course of World War I. At first planes were used only to scout the enemy; occasionally pilots would take pot shots at enemy craft with revolvers or would throw hand grenades at them. Then planes began to be equipped with machine guns; in time the machine gun was geared to the airplane motor so that shots might be fired between the rapidly turning propeller blades.

The airplane now began to play an important part in the war. There were swift little fighting planes, larger and slower observation planes and still larger bombers. The production of planes soared in the warring countries and also in the United States, which did not enter the war until 1917. New models were constantly developed, only to be discarded for still later models. As a result airplane progress was extremely rapid in the course of the four years that the war lasted.

Shortly after the end of the war two great flights showed how much had been

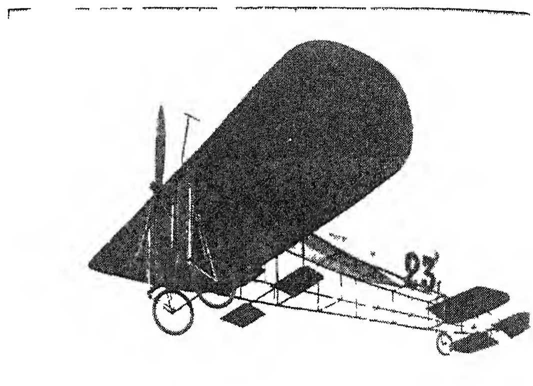
accomplished. In May 1919, the United States flying boat NC-4 flew from New York to Plymouth, England, by way of the Azores and Lisbon, Portugal. A month later, two Englishmen, Captain John Alcock and Lieutenant Arthur Brown, made the first non-stop flight across the Atlantic, flying from Newfoundland to Ireland. The airplane had come a long way since Orville Wright's first hop of 120 feet only sixteen years before!

The governments of the victorious Allies had sold their surplus war planes at low prices. Many former war pilots bought these planes; they used them for "barnstorming" and also to take passengers on short flights. Air-transportation companies scheduled passenger flights; regular airmail service was established Airplane engines were improved; metal began to replace the wood and fabric of the older planes.

On May 10, 1927, Charles A. Lindbergh, a young American aviator, took off from Roosevelt Field, near New York City. Thirty-three hours and twenty-nine minutes later, after a thrill-packed flight through fog and sleet over the Atlantic, he landed at Le Bourget Airport, near Paris, France. This was the first of a number of brilliant flights in 1927 and 1928; the Atlantic and Pacific were crossed again and again. In the years that followed there were other notable flights, which we need not describe here.

British Official Photograph

Testing the engine of a British war plane in World War I in the course of a thoroughgoing overhaul.



Curtiss Wright Corp

The flimsy construction of the Blériot monoplane.

The airplane industry continued to forge ahead with giant strides. The airplane became a major factor in the world's transportation systems. Freight planes opened up to commercial enterprise new areas in the Far East, in Canada, in South America. The military services of the world built up powerful air fleets. Most of these military planes were land based; a considerable number, however, operated from the decks of big aircraft carriers.

It is hard to exaggerate the importance of air power in World War II. If Germany had things all her own way at first in Poland, in the Low Countries, in Norway and in France, it was in large part because the Allies could not match her powerful air fleets. After France's downfall in June 1940, the Germans' aerial bombardment of Britain's cities almost brought England to her knees. Fortunately the Royal Air Force, though greatly outnumbered, fought back so valiantly that it saved the day.

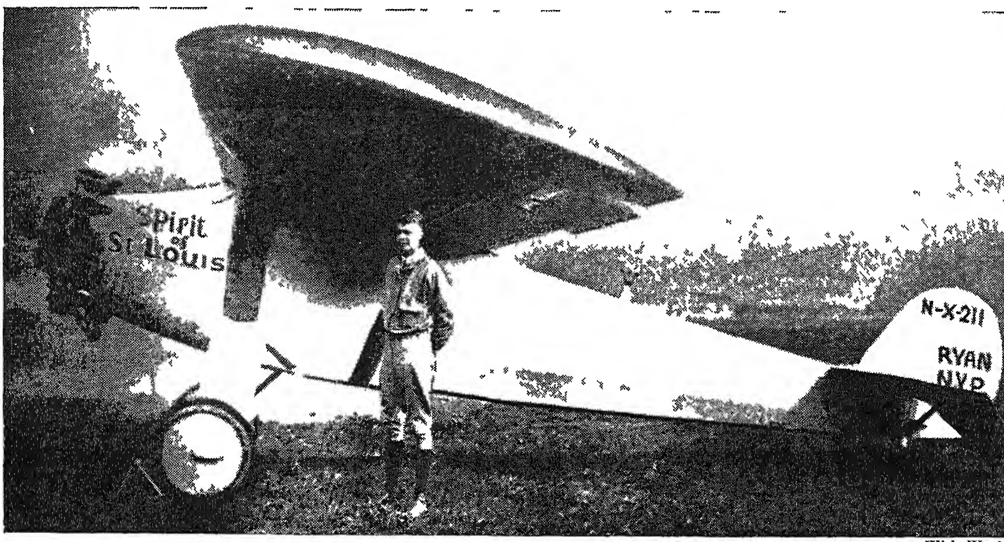
After America entered the war in December 1941, the tide began to turn. America's industrial might was used to turn out bombers and pursuit planes and transport planes in ever increasing numbers. As time went on, the Allies came to rule the skies and the doom of the Axis was sealed. The terrific aerial bombardment of Germany's industrial centers by American and British planes seriously crippled Germany's war production and contributed powerfully to

her collapse. The pounding that Japan took from America's huge superfortresses (B-29's) and from planes launched from aircraft carriers had almost paralyzed the nation's will to fight even before atom bombs fell on Hiroshima and Nagasaki.

Toward the end of the war jet planes made their appearance. These were propellerless craft, which derived their motive force from gases expelled from the rear of the plane. The Germans used a crewless jet plane, called the V-1, to bomb England. (V stood for *Verschaltungswaffen,* or "weapon of vengeance.") V-1's, with high explosives packed in the warhead, or nose, were launched from sites on the west European coast; they flew until their fuel was exhausted and then fell, exploding as they crashed to the ground. An even more dreadful German weapon—the V-2—consisted of a huge explosive-laden rocket which soared fifty miles and more into the upper air and then fell with a speed exceeding that of sound. The Germans also put a jet pursuit plane into the air. It outsped the Allied planes that opposed it but did no particular damage.

Of course air power was by no means the whole story in World War II. Armored columns and infantry, engineers and signal-corps men, submarines and battleships, spies and counterspies all played their part But if there had been no air power, the war would have been entirely different and it might well have ended differently.

After the war, jet planes were greatly improved; their flight range and speed were increased and they were made more maneuverable. The air arms of the world began to build up big fleets of jet pursuit planes and bombers; jet transport planes appeared on the scene. Aviation engineers also worked on giant rockets. Passengerless rockets were sent hurtling more than a hundred miles into the upper air. Men began to dream of rocket ships that would carry passengers to the moon and perhaps even to some of the earth's sister planets. While jet planes and rockets went rushing through space, the far slower but more versatile helicopter flew straight up and down and every which way or hovered almost motionless in the air.



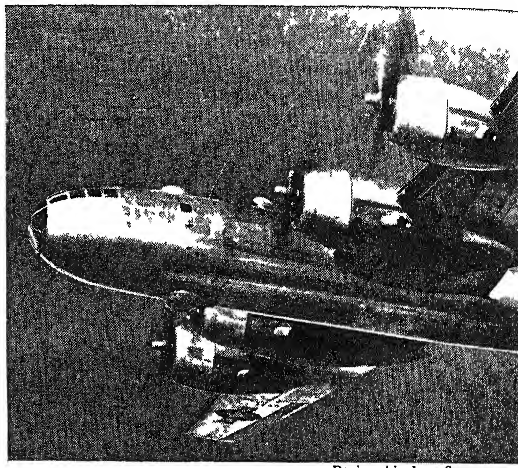
Wide World

Charles A. Lindbergh and the plane in which he made his historic flight across the Atlantic in 1927.

In the meantime vast numbers of conventional air transports, air freighters and private planes went droning through the skies. Few people paid attention to such routine flights, which would have utterly amazed men a few decades before.

The vast majority of heavier-than-air

planes today are provided with propellers driven by gasoline engines. These propellered craft are of many different kinds. There are military planes, large and small, passenger planes, freight-carrying planes, private planes; there are land planes and seaplanes; there are amphibian planes that can take off from and land on either land or sea. But however much these craft may differ from one another, they are all based on the same general principles of flight. These principles hold in large part for non-propellered craft as well, with only a few exceptions.



Boeing Airplane Co

The B-29 Superfortress of the United States Air Force, shown in the above photograph, was the largest bomber to see service in World War II

What makes a plane fly?

One of the most important factors that keeps a plane in the air is the combination of forces that we call "lift." To understand the nature of lift, let us examine the cross section of an airplane wing, like the one shown in the picture on page 2308. Note that the upper surface of the wing is curved, or cambered, and that the leading (front) edge is thicker than the trailing (rear) edge. When the wing moves through the air in flight, the air is deflected upward over the cambered upper surface of the wing. The speed of the airflow is increased and its pressure is reduced in accordance with a law of physics called Bernouilli's Principle. (See Index, under Bernouilli's Principle.) The atmospheric pressure on the underside of the wing has not changed appreciably and it has now become greater than the reduced pressure on top. Therefore the plane is lifted up from below.

If lift tends to keep a plane up in the air, the factor known as "drag" tends to resist its forward movement and to make it more subject to gravity, which tends to pull it down. The principal cause of drag is the large amount of frontal area that must be pushed against the air. This is called "parasite drag," because it is produced by surfaces that do not contribute to lift.

To help offset parasite drag the airplane designer uses streamlining, thereby reducing the frontal area that must push against the air. We discuss streamlining in detail elsewhere. To show how truly effective it

National Military Establishment

Crew and maintenance men lined up in front of a B-36, a huge bomber of the United States Air Force.

is, let us point out that the drag of a streamlined B-29 superfortress with its wheels retracted or drawn inside its body is equal to the drag of the nonstreamlined landing gear when the wheels are down.

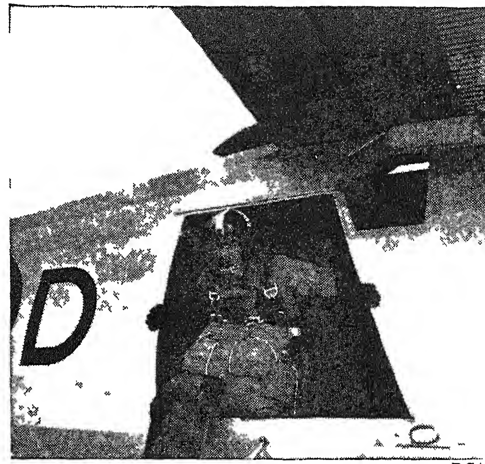
Another type of drag is skin friction—that is, the friction of the air molecules against the skin, or outer surface, of the airplane. We can reduce skin friction by using flush rivets in place of round head rivets and by polishing the wing, fuselage and tail surfaces. A waxed airliner is more attractive than an unwaxed one; it is also speedier.

Even when there is a maximum amount of lift and a minimum amount of drag, a plane must have some source of power to drive it through the air. In the propellered plane, the power plant is a highly efficient gasoline engine. Airplane engines weigh much less than automobile engines of the same horse-power; the ratio is something like five to one. The reduced weight of the airplane engine is due to the use of aluminum and magnesium alloys and strong lightweight alloy steels.

The motors of airplanes

The simplest of all airplane motors are the in-line engines, in which the cylinders are arranged one behind the other. In the horizontally opposed type, the cylinders are set horizontally with half the number distributed to the right and the other half to the left of the crankshaft. The cylinders of V-type engines are set at an angle, one behind the other, in two rows; viewed from the front, these rows form the letter V. In the radial engine, the cylinders are arranged like the spokes of a wheel around a hub formed by the crankshaft. To provide increased horse-power, multiple bank radial engines have been developed; in these a second row of cylinders is placed behind the cylinders of the forward row. As many as four banks of cylinders may be used.

The number of engines in a plane ranges from one to eight. Occasionally planes with as many as twelve engines have taken the air; but these have all been experimental models. The single engine of a light plane is set in the nose of the craft; generally



RCAF

A para-rescue man of the Royal Canadian Air Force, about to make a parachute jump. He will bring medical and other aid to ground troops

multiple motors are placed upon the wings. The engines of flying boats are set above the wings.

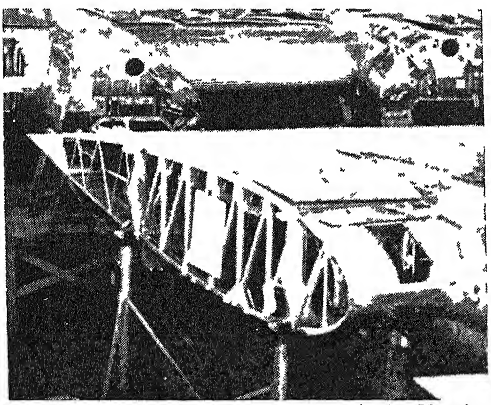
Engines of more than three hundred horse-power are generally provided with superchargers. The supercharger, operated by the engine, compresses the air that is drawn in from outside the plane and that is combined with gasoline vapor to form an explosive mixture. The supercharger provides more power for take-offs. It also makes engine performance more efficient at high altitudes by compressing the rarefied air that is found at these heights.

The power generated in the airplane motor or motors is applied through one or more propellers. The propeller, which has from two to four blades, is really a screw that cuts its way through the air much as a wood screw cuts through wood or the screw of a vessel cuts through water. The forward force or thrust produced by the propeller has the task of overcoming the total drag. If the thrust is greater than the drag, the airplane accelerates. It flies at constant speed if the thrust equals the drag; it loses speed if the thrust is less than the drag.

The blade of a propeller is an airfoil, with the cambered surface in front. Formerly all propeller blades were made of wood. Nowadays the blades of low-powered planes are made of laminated wood, while those of larger and more powerful craft are usually

made of alloys of aluminum or magnesium.

The pitch of propeller blades—the angle at which they are set—has an important bearing upon flight. When we say that a blade has a low pitch, or a flat angle, we mean that it is approximately at right angles to the propeller shaft. In this position it takes a more powerful "bite" of the air than in any other. The higher the pitch of the blade—the more it veers from the perpendicular position—the farther the blade can screw the plane forward with each revolution, but the less powerful its bite is. Hence a low pitch is preferable at take-offs, when most power is required. After the plane has gained momentum in the air, it is



Aviation Magazine

Cross section of an airplane wing, showing the cambered, or curved, construction of the upper surface

not necessary for the bites to be so powerful and so a higher pitch is preferable.

In some planes, the propeller can be full-feathered: that is, the pitch can be changed so that only the edges of the blades are turned toward the wind. This arrangement is particularly desirable when the plane is gliding with its motor shut off, since a propeller has least drag when it is full-feathered.

Some propellers—particularly those of low-powered planes—have a fixed pitch; the angle at which the blades are set always remains the same. Other craft, including all high-powered models, have controllable pitch propellers, which can be changed by the pilot or which are automatically changed while the plane is in flight. This is done by a mechanical system operated by hand, or by oil pressure acting upon diaphragms or by a small electric motor. In some planes the blade angle can be reversed.

How a plane is controlled in flight

In order to make a plane maneuverable in flight, the pilot must change its position, or "attitude," by means of controls. He works the rudder by means of pedals; he works other controls by manipulating a joystick, a lever that rises directly in front of his seat. (It was originally called the Joyce stick, after its inventor.) In large planes the joystick is replaced by a steering column provided with a wheel.

In light planes, the joystick and the rudder pedals operate the controls by a system of levers, pulleys and screw jacks. In large planes, hydraulic devices, electric motors and various mechanical "boosters" help the pilot to move the bulky control surfaces.

An adjustable horizontal tail surface causes the airplane to climb or descend. Only the rear half—the elevator—of this surface is movable. When the pilot pushes the stick or control column back, the hinged elevator swings upward. The airflow hits the raised elevator; it forces the tail down and the nose upward; the airplane then begins to climb. When the stick or control column is pushed forward, the hinged elevator swings down. The airflow hits the lowered surface, forces the tail up and puts the airplane in a diving attitude.

To change the lateral, or side-to-side, attitude of the airplane, movable parts of the trailing edges of the wings are used. These movable surfaces are called ailerons; they are located near the tips of the wings. In some models the ailerons are not in the trailing edge but are set ahead of it; in these models each aileron has a lower and an upper half that disappears into the lower and the upper wing surfaces, respectively.

The ailerons are worked by pushing the stick or turning the control wheel to the right or to the left. In so doing, the lift on one wing is increased, while that on the other is lessened. One wing, consequently, is raised, the other is dropped and the plane

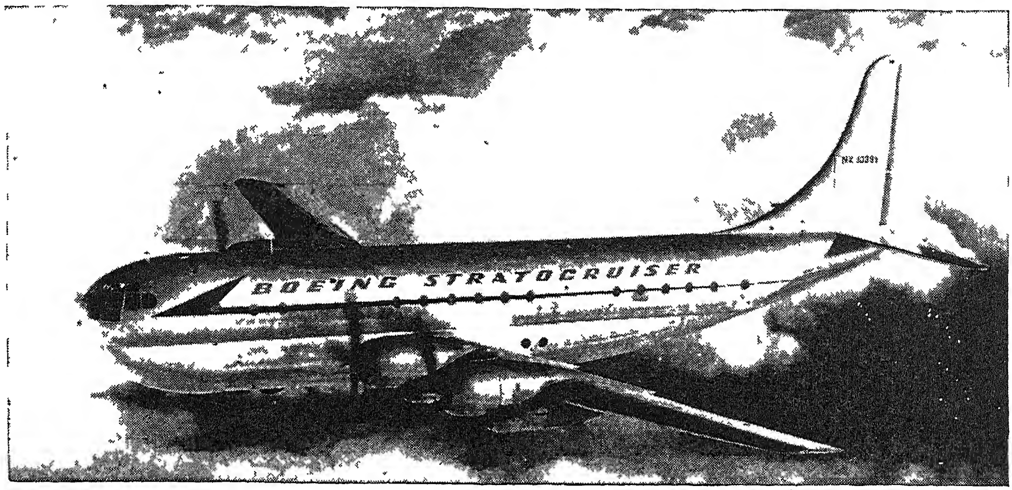


Photo and diagram, Boeing Airplane Co.

The Boeing Stratocruiser carries its passengers in comfort three or four miles above sea level

is in the position known as a "bank." A continued bank will make the plane turn.

To make a turn the pilot uses the rudder as well as the appropriate aileron. The rudder forms part of the vertical tail surface; it is the rear movable half. It turns toward the right when the right rudder pedal is pressed; to the left, when the left pedal is pressed.

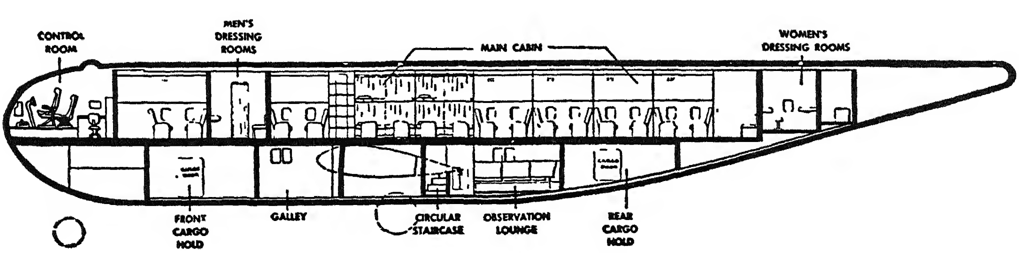
When an airplane runs out of fuel or the engine fails, it can continue to fly by gliding earthward. The average light plane can glide a distance equal to from seven to eight times its original altitude. Skillful pilots learn to set the plane in an attitude that will produce the longest glide.

What we would find in a typical air liner

The supreme development of the propellered airplane is represented by the big passenger transport plane and the huge bomber of the military services. To have some idea of the amazing advances that have been made in the field of aviation since the Wright brothers first flew their "crate" of fabric and wood and wire, let us see what we would find in a typical air liner.

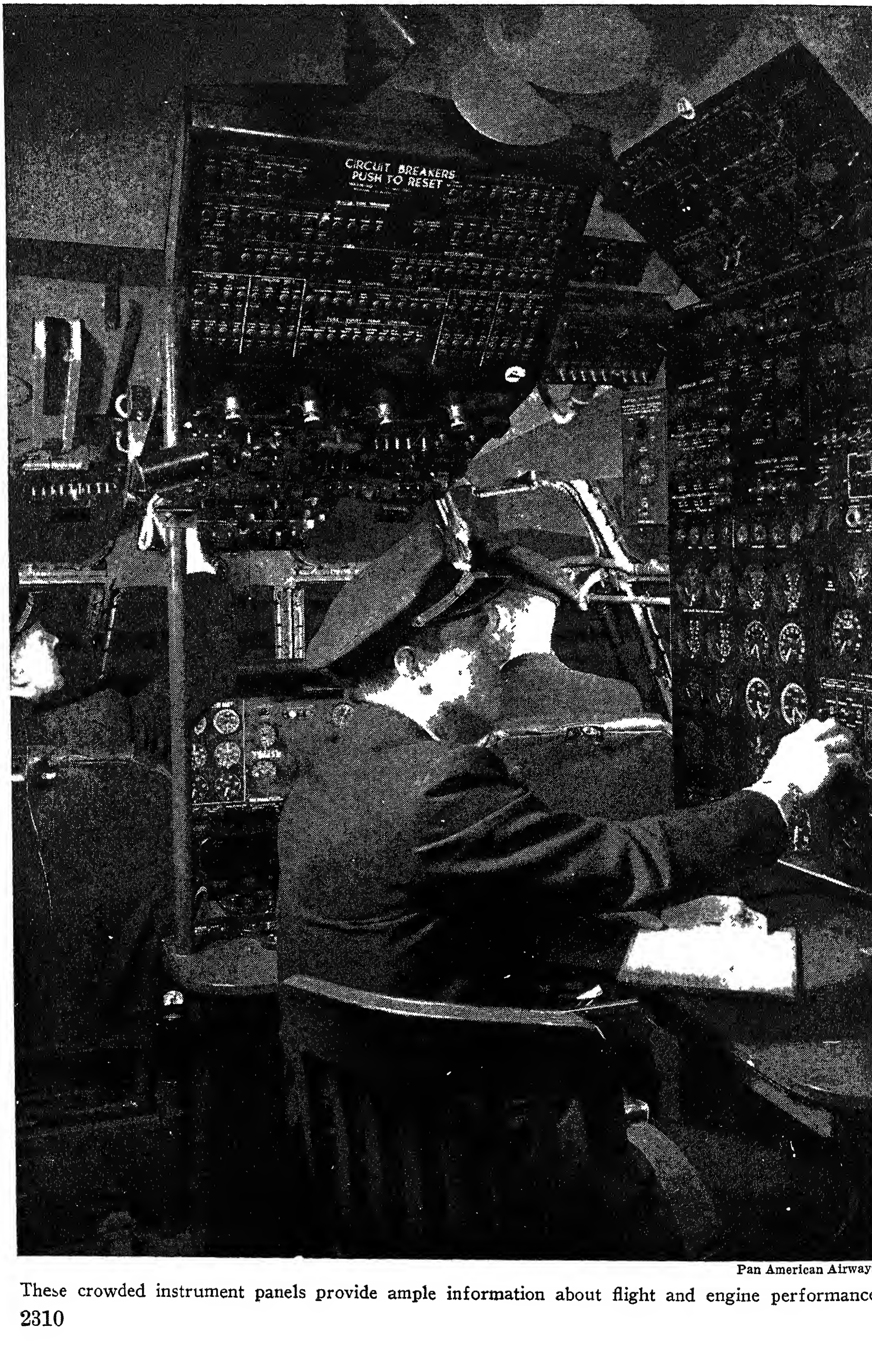
First of all, there is the fuselage, or body, which carries the weight of the crew, passengers and cargo as well as the galley, the ventilating apparatus and the radio equipment. The fuselage must also support the weight of the wings and, consequently, the weight of the structures supported by or suspended from the wings—the engines, the fuel tanks and the landing gear. Some airplanes also carry fuel tanks in the fuselage.

The principle of construction of the fuselage is that of a hollow column or cylinder. In small planes the fuselage may be all in one piece; it is constructed of either plywood or metal. In big planes it is generally made up of sheets of aluminum alloy



This cut-away drawing shows the cabin arrangement of a seventy-two-passenger Stratocruiser. Sleeping accommodations are available in the big plane for thirty-six persons. Note the ample space for cargo.

THE NERVE CENTER OF AN AIR LINER



Pan American Airways

These crowded instrument panels provide ample information about flight and engine performance.

riveted into sections and reinforced by hoops of steel and by stiffeners, running parallel to the length.

Air liners destined for high-altitude flight are provided with pressurized cabins. In these the air pressure found at 8,000 feet is maintained, when the plane rises above that altitude, by means of an air compressor—the cabin supercharger. Pressurized cabins are of two kinds. In one type the cabin is an independent unit inside the fuselage. In the other type the walls of the fuselage serve as the outer walls of the supercharged cabin.

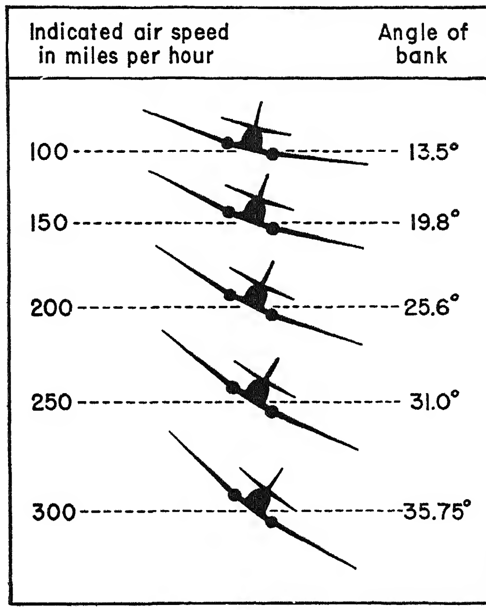
The windows in the fuselage are made of an acrylic plastic called Lucite or Plexiglas. Pilot windshields, or windscreens, as they are sometimes called, are of very heavy shatterproof glass in order to protect the pilot and co-pilot from injury when birds crash into the windshield.

How space is allotted in a modern air liner

The galley is generally located at the rear of the passenger quarters; the lavatory, aft of (behind) the galley. Ahead of the passenger quarters are the baggage compartments; baggage and cargo are also carried in the space below the passenger floor in some planes. The compartments of the navigator and flight engineer are ahead of the baggage room. On the roof above the navigator's compartment there is a transparent plastic dome, called the navigator's astrodome; it is used for taking sights of heavenly bodies with the sextant or octant. The pilot and co-pilot sit in the nose of the plane; the radio operator is stationed behind the pilot. These arrangements differ, of course, in different planes.

The wings are reinforced in much the same way as the fuselage. As we have seen, they carry the engines, the main landing gear and the fuel and oil tanks. During the winter months the leading edges of the wings are equipped with rubber blankets, called de-icers. A device operated by engine-driven vacuum pumps alternately inflates and deflates the de-icers in order to break off any ice that may be forming upon the wings. In some planes a different kind of de-icer is employed Air heated by the engine exhaust and circulated through pipes keeps the wings warm and prevents the formation of ice.

Hydraulic pressure is used to operate a number of devices on an air liner; among other things it serves to lower and raise the landing gear, to work the brakes and to open and shut the engine-cowl flaps, which control the amount of air admitted for cooling purposes. The hydraulic fluid used in



The above table shows the recommended angle of bank at several different air speeds, as indicated by the bank-and-turn indicator. The planes shown in silhouette show the attitude of the plane in each of the angles of bank indicated in the table

modern planes is a thin petroleum-base oil containing special antifreeze and antirust compounds. If the main hydraulic system fails, controls are generally operated by hydraulic power provided by hand pumps.

Every air liner has an elaborate electrical system. It is equipped with from two to four engine-driven generators and the same number of storage batteries. To save the batteries, the engines are started by an outside source of current, plugged into the air liner at the airport. This source is either a heavy-duty 24-volt battery carried on a cart or a portable 28-volt D.C.

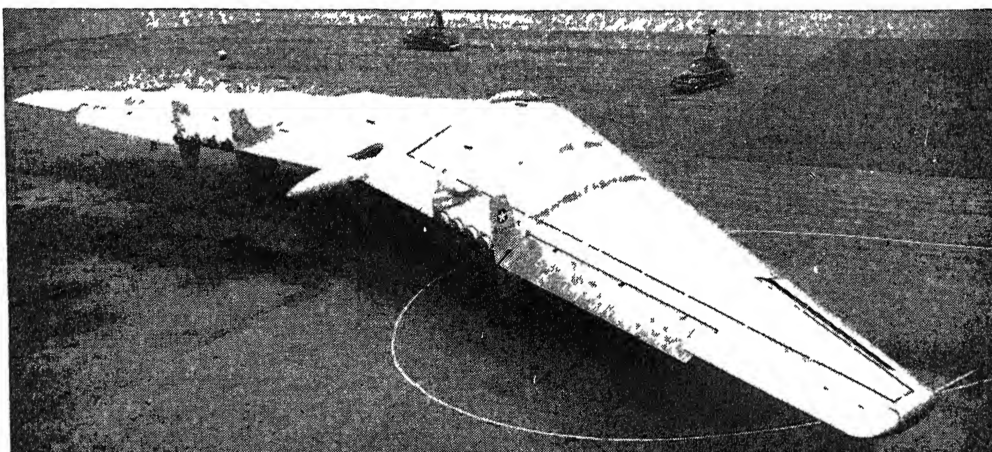
(direct current) generator, driven by a gas engine.

In the average big air liner some two hundred devices are electrically operated. Of course the radio equipment and the cabin, landing and navigation lights use electric current. Electric motors run the fuel pumps; they change the pitch of certain kinds of propellers; they work the pumps that spray de-icer fluid on the windshield. Many of the engine instruments are operated by electricity. However, the spark that fires the mixture of gasoline and air in the cylinders is not produced by the plane's electric system, but by magnetos turned by the crankshaft.

The fuel is stored in rubber self-sealing cells or in aluminum tanks and is carried into the tube. The changes in air pressure cause a metal disc to move up and down; the disc movement affects the indicator of the airspeed dial on the instrument panel The rate at which the plane is rising is indicated by the rate-of-climb indicator, or variometer.

The altimeter is an aneroid barometer, which records the plane's altitude above sea level. (See Index, under Barometers—Aneroid.) Like all barometers, the altimeter is affected by atmospheric pressure, which lessens as the altitude increases, changes in pressure are registered in terms of feet on a dial.

The terrain-clearance altimeter indicates the distance of the plane from any obstruction on the earth's surface. This instru-



Northrop Aircraft, Inc.

Northrop Flying Wing YB-49. Crew quarters, cargo space and power plants are housed within the wings.

to the engines in rubber hose or aluminum-alloy tubing. Each engine usually uses an independent oil system; but in some air liners it is possible to transfer oil from one engine to another.

On every large air liner there are a great many instruments that provide information about the flight of the plane; they are grouped on the panel in front of the pilot and co-pilot.

The airspeed indicator shows the speed of the plane in flight. Air is admitted to the pitot tube, a metal spike that extends forward from the airplane wing. The more rapidly the plane moves, the more air rushes

ment sends a short-wave radio signal toward the ground; the signal is reflected back from the earth and is recorded. The time required for the round trip of the signal varies according to the distance of the plane from the surface of the earth. As in the case of the barometric altimeter, variations are registered in terms of feet. The instrument quickly tells the pilot when he must climb higher in order to avoid a mountain peak or similar obstacle in the path of the plane. Some planes are equipped with a radar set (see Index, under Radar), which shows the pilot where he is and warns him of near-by mountains or storm clouds.

The bank-and-turn indicator shows the correct angle of bank for a given speed; the greater the speed, the greater the recommended angle of bank. In the table on page 2311 we show the angles indicated for several different air speeds.

The gyro-artificial horizon shows the pilot the attitude of the plane in the air; it indicates whether the nose of the plane is low or high and whether or not the plane is banking. Air liners are generally provided with an automatic pilot, operated by two gyroscopes. Once the automatic pilot is set, it keeps the plane on its course.

Several kinds of compasses are used in an air liner. First of all there is the conventional magnetic compass. The gyrocompass, or directional gyro, has a gyroscope instead of a magnet. If an airplane turns, the gyroscope remains in its former position, while the indicator line of the dial turns with the airplane. The radio compass has a needle that moves in response to radio waves sent out by radio-range stations. The gyro fluxgate compass picks up the electric currents that surround the earth; by means of an amplifier, it makes these currents strong enough to move a compass needle.

There are other flight instruments besides those that we have just mentioned. There are also a number of instruments that continuously record the performance of the engines. They indicate the air pressure, the temperature, the rpm (revolutions per minute) of the engine crankshaft and the amount of fuel in the tanks.

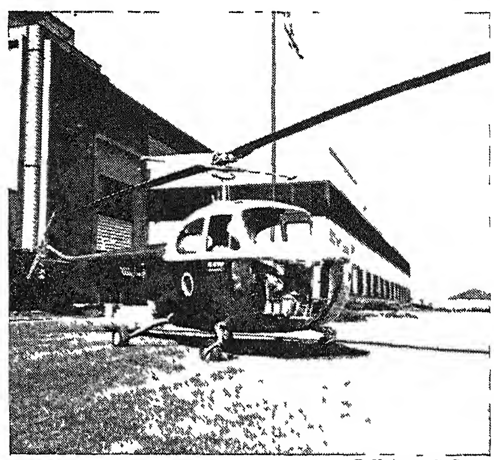
The flying wing of Northrop and Burnelli

No account of propellered craft would be complete without at least a mention of the "flying wing," the creation of Jack Northrop and Vincent Burnelli. They had been struck by the fact that the fuselage represents so much dead weight and does not contribute in the slightest to keep the plane in the air. Hence they developed the flying wing, a craft in which there is no fuselage at all; the crew, passengers and cargo are all carried in the wings. The flying wing has been flown successfully, but it has not passed beyond the experimental stage.

Planes with rotary wings: the autogiro and the helicopter

The conventional propeller has disappeared entirely from the strange-looking plane known as the helicopter; instead we have a rotor, consisting of propeller-like rotary wings, which whirl above the fuselage.

The first successful rotary-wing plane was the autogiro, invented by the Spaniard Juan de Cierva, which was first flown successfully in the summer of 1923. This craft was provided with an ordinary propeller as well as with a rotor. The propeller provided thrust in order to get the autogiro off the ground and to keep it moving through the air. At the take-off the rotary wings were rotated by means of a special connection with the engine. Once the autogiro was in flight, the rotor was disconnected from the engine; its blades continued to turn because of the air moving past them. The autogiro had no wings; the pilot controlled it in flight by the use of standard tail surfaces and by tipping the rotor.



Bell Aircraft Corp.

The helicopter is the most versatile of airplanes.

The autogiro has been supplanted by the helicopter, which has done away entirely with the propeller and the tail assembly. Many pioneers in the field of aeronautics worked to develop this revolutionary type of plane; foremost among them were the German Heinrich Focke, the Frenchman Louis-Charles Bréguet and the Russian-

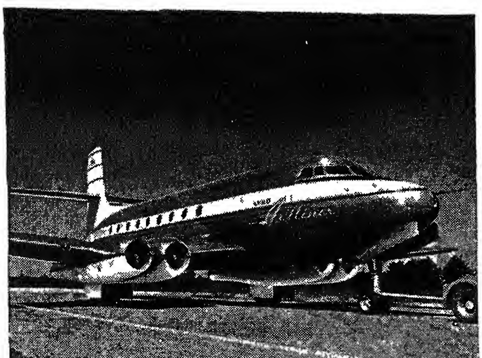
born American Igor I. Sikorsky.

The rotary blades of the helicopter are turned continuously by the engine. The rotor is not connected to the motor when the the engine is warmed up; when the pilot is ready for the take-off, he throws in a clutch; this engages a gear and the rotor begins to turn. The helicopter then starts to climb, vertically if need be.

The helicopter is controlled by changing the pitch of the blades; change of pitch can be made at any point along the 360 degrees of rotation. When a given change in pitch, for example, causes bites of air to be taken on the forward side, the helicopter moves forward; if the pitch is changed so that the blades take bigger bites at the rear of the plane, it moves backward. In climbing or descending vertically, there is no pitch change.

A problem that all helicopters face is the tendency of the fuselage of the craft to rotate in the direction opposite to that of the rotor blades. This tendency is called "torque." The most common method of correcting torque is to mount a small engine-driven rotor, turning on a horizontal axis, on the tail. This rotor—the contra-rotating rotor—causes the fuselage to move in the direction opposite to that produced by torque; the two forces neutralize one another. Some helicopters have more than one contra-rotating rotor.

The helicopter is much slower than a propellered craft of the same horse-power. Its great advantage lies in its maneuverability. It can take off from and land on extremely narrow surfaces such as rooftops or the decks of ordinary ships; it can hover at about the same place for a long time. In several cities, air mail has been carried by helicopter from the roof of the central post office to waiting air liners at the nearest airport. The helicopter has proved its worth in rescue work at sea; it can take off the occupants of a distressed craft or a lifeboat while hovering over it. In the Korean war helicopters have been employed to rescue flyers who have bailed out behind the enemy lines.



A. V. Roe Canada Ltd.

A Canadian Avro Jetliner, powered by jet engines.

Jet propulsion: turbojets, propjets and ramjets

In both propellered craft and helicopters. revolving blades cause the plane to move by screwing its way through the air. Jet-propelled planes are based on an entirely different principle. In the most widely used type of jet plane, the turbojet, air is drawn into the engine while the plane is in flight. It is compressed by a rotating compressor; then fuel is injected into it

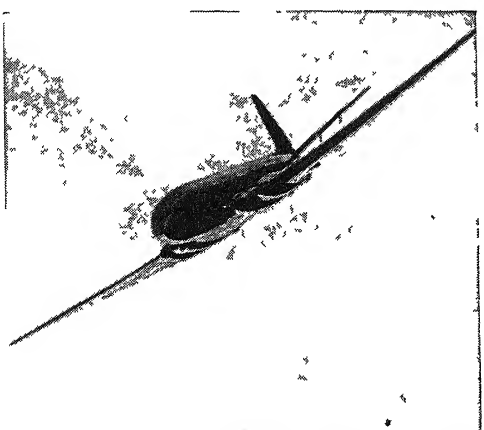
Republic Aviation Corp.

America's swift Thunderjet P-84 jet fighter plane.

and the mixture is burned. The hot gases pass through a gas turbine, whirling it around; this turbine furnishes the power for the compressor. After the hot gases leave the turbine, they enter a specially shaped chamber in which the pressure they exert is raised. Finally the gases are ejected at high speed through a nozzle at the rear of the plane.

The jets of hot gas spurting from the nozzle provide the plane with its motive

power. At one time it was believed that these gases struck the air at the rear of the plane and then bounced back, causing the plane to move forward. What really happens is this. After the air has been compressed and heated it pushes violently in every direction—up, down, sideways, forward, backward. The pressure is released at the rear of the plane as the gas escapes through the nozzle. But the heavy pressure against the front part of the plane continues.



British Information Services

Britain's deHavilland Comet, a jet air liner.

There is no longer any counteracting force in the opposite direction; hence the pressure against the front of the plane drives it ahead.

The principles of jet propulsion and of propellered flight have been combined in the propjet, in which a turbojet engine drives not only the compressor but also a propeller. Even as the propeller is spinning, the hot gases still continue to shoot through the nozzle, thus producing an additional source of power. The chief reason for using a jet engine instead of a conventional engine to drive the propeller in a propjet is that the jet engine is more efficient. In the conventional engine the pistons within the cylinder have an up-and-down motion that has to be converted into rotary motion in order to turn the crankshaft. In the turbojet motor, the rotary motion of the spinning turbine can be applied directly to the crankshaft.

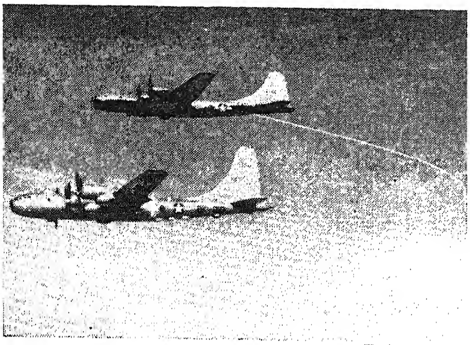
Another type of jet-propelled plane is the ramjet, which is also called the "flying stovepipe" because of its simplicity. No compressor is used in this model. When the plane is in flight, air rushes into the front end and enters the combustion chamber, where fuel is injected into it. Combustion takes place; the hot expanding gases leave the chamber and provide jet propulsion in the same manner as in the turbojet. Since the ramjet does not have to use up some of the power of the escaping gases to drive a turbine, these gases produce greater thrust than in the case of the turbojet. On the other hand air must enter the front end of the plane at high speed if the plane is to function efficiently. Hence the ramjet must be launched at high speed either from another plane or, if it is to take off from the ground, by rockets.

Rockets as a source of power for planes

Rockets are propelled in somewhat the same way as jet-propelled planes: that is, fuel is ignited within them, gases escape from the rear and the rocket is thrust forward until its fuel has been exhausted. The great difference between the rocket and the jet-propelled plane is that the rocket carries its own supply of oxygen while the jet plane must obtain its oxygen from the atmosphere. When rocket-powered planes are perfected, they will be able to fly in the upper reaches of the stratosphere or perhaps even beyond it. We describe rockets in detail in another chapter. (See Index, under Rockets.)

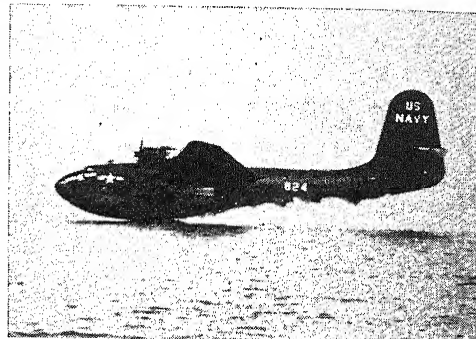
The glider still has a place in aviation

We now come to the motorless airplane that we call the glider. This ancestor of the powered plane has been eclipsed by its numerous offspring, but it still maintains a place, however modest, in the field of aviation. It has much the same arrangement of wings, tail, body, landing gear and controls as the conventional propellered craft; but the motor and propeller and all the equipment that goes with them are missing. Gliders are generally launched by automobiles or powered planes; sometimes



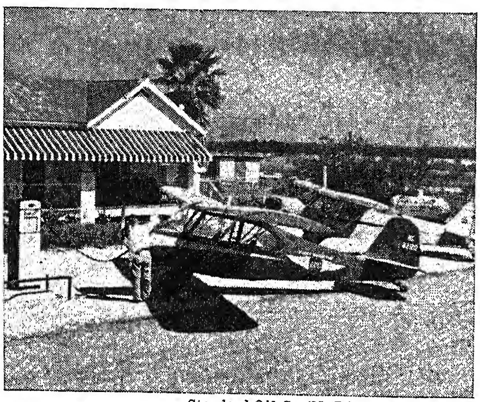
U. S. Air Force

How a plane takes on fuel while it is in flight.



Glenn L. Martin Co.

The Caroline Mars, a huge U. S. Navy flying boat.



Standard Oil Co (N. J.) Photo by Rotkin

Airplane taking on gas at a corner grocery store.

they are catapulted upward into the air.

Undoubtedly the most spectacular kind of glider is the sailplane, or soaring glider. It is so light and has such low drag that it can ride thermals, or ascending currents of air. This is how such currents are formed. During sunny days, fields, forests, lakes and ponds store up a good deal of heat. After the sun sets, the air near such surfaces is warmer than the cool night skies; hence it moves upward until it is cooled at the higher levels of the atmosphere. Thermal currents are also found in cumulus clouds. By taking advantage of all these rising air currents, skillful sailplane pilots can perform almost incredible feats. Already sailplanes have soared over 22,000 feet in the air; they have covered more than 400 miles; they have remained aloft for over 50 hours.

More sturdily built gliders have been used to carry freight and military personnel and equipment. During World War II, gliders towed by powered planes were employed by both sides to transport fully armed troops, light artillery, ammunition and even jeeps.

A plane owner in a sparsely settled area may fly from a pasture on his farm or ranch to a friend's farm or ranch with comparatively little preparation or fuss. But the average flight is a much more complicated affair. The pilot must be sure that the motor (or motors) and the controls are in perfect operating condition, because failure in the air may result in a disastrous crash. He must keep informed of weather conditions along his route. He must obtain clearance at the airport before he can take off; he must observe traffic rules at the airport and in flight. He must be familiar with the devices that are intended to keep him on his course when visibility is good and when it is bad. He must be careful at all times to keep clear of obstacles in his path; he must always be prepared, too, to make an emergency landing in the event of engine trouble. Even when he reaches his destination, landing may be a nerve-racking experience if traffic is heavy, or if visibility is poor.

Airports, where most flights begin and end

Most flights begin at one airport and end at another. Airports range from grassy meadows, where planes can take off and

land and obtain gasoline and oil, to giant fields, provided with long concrete runways and equipped to provide service for all kinds of aircraft. Large airports have hangars for the storage and repair of planes, offices for operations managers, dispatchers, radio operators and weather forecasters, and waiting rooms and restaurants for passengers.

Seaplanes take off and land at seaplane bases. These are located in sheltered spots, where the water is deep enough even at low tide. Seaplane bases are generally provided with ramps for moving seaplanes.

Aboard an air liner in flight

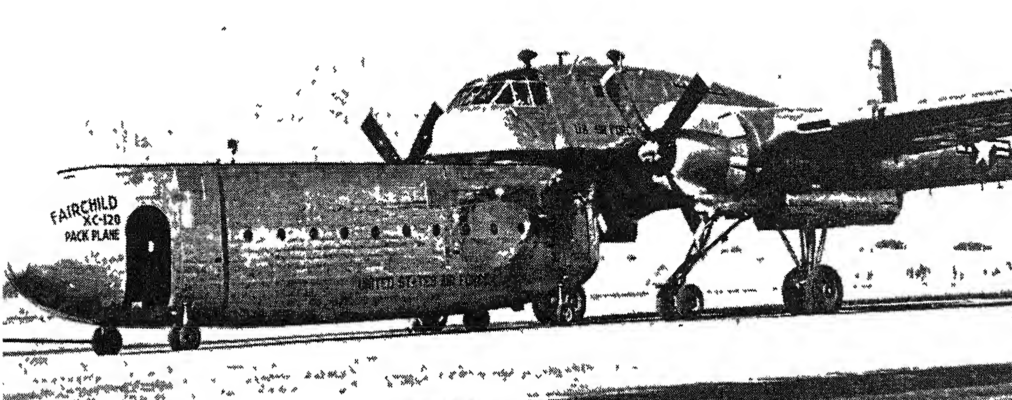
Let us board the big air liner that we described before as it prepares to take off on a regularly scheduled flight from one airport to another. The big ship has already been checked by mechanics; it has taken on gas and oil. Full information has been obtained about weather conditions along the proposed route. The pilot has filed a flight plan with the airport authorities; this plan includes the direction and altitude of flight.

He now makes contact by radio with the control tower of the airport. He gets the exact time, the speed and direction of the wind and special instructions concerning traffic at the airport. He is told what taxi strip to use in taxiing over to the take-off position. At last the signal is given, and the big plane rises from the ground; when it is well under way it retracts its landing gear. It remains in radio contact with the control tower for some time.

The plane is now on a definite air route and headed for its destination. The airway is almost as well defined as the highways along which automobiles make their way. It has a definite height and width; and the pilot is supposed to remain in it.

Airplanes must obey traffic rules while in the sky; these rules vary from one country to another. In the United States, airplanes proceeding eastward (also to the northeast and southeast) fly at odd-numbered thousands of feet; those proceeding westward (also to the northwest and southwest) fly at even-numbered thousands of feet. Eastbound and westbound planes have the right of way over northbound and southbound planes at the places where airways intersect. That means that northbound and southbound planes must drop five hundred feet in crossing an intersection, while eastbound and westbound planes maintain their altitude.

The navigator follows the course of the plane on maps or charts. The pilot keeps the ship on the course in any sort of weather



Fairchild Aircraft

The Fairchild XC-120, the "flying boxcar" of the U. S. Air Force, has a detachable understructure.

by following the signals sent out by radio transmitters, called radio ranges. These ranges are located at a number of points along the airlane. They send out the Morse code letters A (. —) and N (— .) along a beam. Near the edge of the beam one or another of these letters will come in strongly on the plane's receiver; the pilot will hear a succession of . —'s or — .'s. In the center of the beam the . — signal blends with the — . signal; the pilot then hears one continuous tone. When the plane passes over the radio range, the signals stop. This area is called the "cone of silence." In some cases a special transmitter, located in the path of the beam, warns the pilot that he is about to enter the cone of silence.

Another method for keeping a plane on its course is the high-frequency omnirange system. It is appropriately named, for an omnirange station sends out radio beams in all directions, whereas radio ranges send signals in only four directions. The pilot receives omnirange signals on a special receiver; they enable him to determine his direction with respect to the omnirange station sending out the signals. Omnirange is equally useful for navigation on airways or off airways. Since it operates on very-high-frequency bands, the signal is virtually free from any type of static interference. Thus the pilot can receive omnirange signals at all times, even in the midst of a thunderstorm.

Light beacons are useful when visibility is good

For night flying when visibility is good, the pilot finds light beacons useful. Each of these beacons flashes out in Morse code the first letters of certain words, arranged in a definite order and repeated at regular intervals.

The pilot now approaches the airport where he is to land; at night he recognizes it by a revolving beacon that sends its rays circling through the darkness. He calls the airport's control tower by radio. He reports the number and model of the plane, the airline to which it belongs, its position, altitude and air speed; he asks the flight dispatchers for landing instructions.

If the air traffic at the airport is heavy, the pilot is told to circle the landing field at a definite altitude and air speed. Planes flying at different altitudes, waiting for a chance to land, are said to be "stacked." Each plane in the stack keeps 1,000 feet above the next lower one. The lowest of all, flying at a height of 1,000 feet, is the first to land; each of the other planes then drops 1,000 feet. Newly arrived craft go to the top of the stack.

If visibility is good during the daytime, landing is a comparatively simple matter, once clearance has been given. At night, too, under favorable conditions, the pilot has little difficulty in bringing his plane to the ground. The edges of runways are illuminated by small lights sunk flush with the runway; red warning lights or red patterns of light are used on all obstructions in the vicinity. A line of lights across the runway shows where it comes to an end.

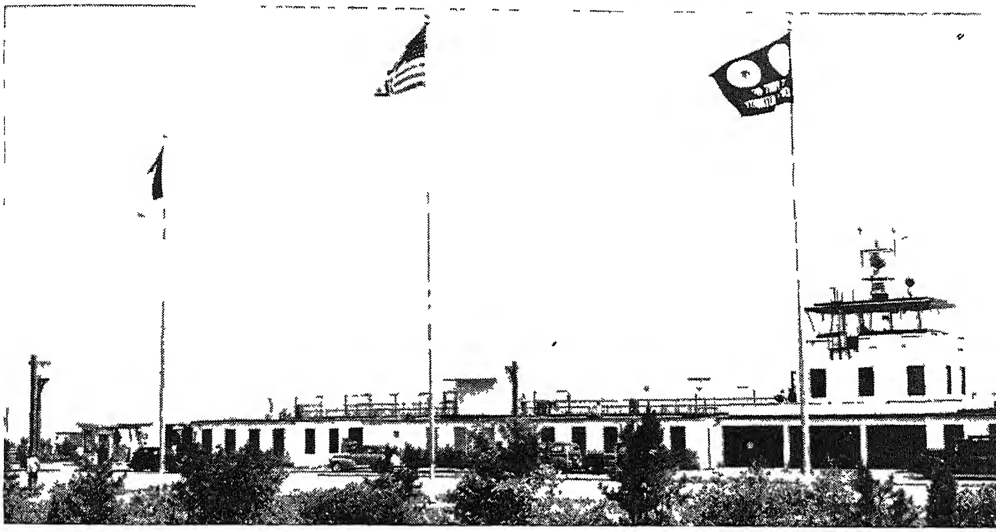
Even small airports have a system of traffic control

A plane without radio equipment is not permitted to use a radio-controlled airport, except in an acute emergency. But even at smaller airports without radio facilities, pilots cannot take off and land at will. Operators on the ground give instructions to arriving or departing planes by means of green and red signal lights. These lights are flashed from a device called a "biscuit gun"; it is held in the hand by means of a pistol grip and is operated by a trigger. At the take-off a red light is a signal to halt; the green light gives clearance to the pilot. A red light warns incoming planes to continue circling the field; a green light means that the plane can land. The biscuit gun is used by day or by night. Sometimes red and green flags serve for signaling purposes in the daytime.

Sometimes the control tower reports to the incoming pilot that visibility is poor or nil at the airport. If the plane is not specially equipped to make landings under such conditions, it proceeds to another airport.

Nowadays many planes, particularly military planes, make landings safely when the landing field is invisible because of fog. If

AT A BIG MODERN AIRPORT



View of the New York International Airport, often called Idlewild. The airport is in the southeastern section of Queens County, in Greater New York City, and borders on Jamaica Bay. It covers 4,900 acres and is the largest commercial airport in the world. The first flights here began on July 1, 1948.

Both photos, Port of New York Authority

Control tower of the New York International Airport. Flight dispatchers stationed here give instructions by radio to planes that are about to take off or land. If traffic in the air is especially heavy, they assign the levels at which incoming planes circle the field until they can make a safe landing.

an airport is equipped with an Instrument Landing System (ILS) the pilot can bring his plane in without looking outside of the cockpit. A transmitting station at the far end of the runway sends out a pair of horizontal beams, like those sent out by radio range; both beams are on the same radio frequency and can be received in the aircraft by a single radio receiver. The pilot keeps his plane between the two beams: he is then said to be on the localizer course. A second transmitter sends out another pair of beams, one above the other. As long as the pilot keeps within the second set of beams, he knows that he is coming down properly: he is said to be on the glider path. He learns how far he is from the end of the runway by a series of "fan marker" transmitters, so called because each one sends a fan-shaped beam straight up in the air. When the pilot passes through the vertical beam of the boundary marker at the airport, he knows that he is at the landing field. If he is still squarely on the localizer course and the glide path, he will land in about four seconds.

A complete instrument landing is apt to be rather rough. Fortunately, however, it is rarely necessary to make such a landing, since even in the worst kind of weather the runway marker lights can usually be seen when the aircraft is still a few feet off the ground.

The blind landing system called Ground Control Approach

Another effective type of blind landing system is Ground Control Approach, or GCA. Two radar sets are operated at the landing area. The screen of one set shows a picture such as the operator would see if he were high in the air over the runway and looking down toward the ground. The picture shown in the other screen shows what the operator would see if he were on the ground far off to one side of the runway and looking toward it. The operator can also see the incoming plane in both screens. He talks with the pilot of this plane by radio; he tells him how to shift his course, if necessary, in order to keep headed for the runway and to remain in the proper glide path; he also informs him how far he is from the touchdown point (the place where the wheels should touch the ground).

How the airplane serves mankind

The uses of the airplane are legion. The airplane provides by far the swiftest form of passenger transportation. It has linked together the countries of the world by a maze of air lines. It has revolutionized the world of commerce. It has enabled men to open up new mineral and timber resources in regions where there is practically no land or sea transport; it makes possible rapid long-range hauling of foods and livestock.

The airplane has been a vital aid to the forest ranger in patrol work. It quickly brings skilled doctors and nurses to out-of-the-way places where disaster has struck or where epidemics threaten. It is immensely helpful to the farmer: low-flying craft spray the crops with poisonous chemicals that kill insect pests. We know much more about hurricanes than ever before because big planes have deliberately flown into the path of these destructive winds so that scientists could study them at close range.

The airplane has been a boon to geographers. It has made it possible to survey quickly and accurately vast areas such as the frozen wastes of the north and south and the forbidding jungles of Africa and South America, which were formerly only sketchily outlined on our maps. Photographs taken from the air have been combined to form highly effective relief maps.

But the plane has not been an unmixed blessing for mankind. As we have seen, it has been a terribly effective weapon in modern warfare. It has extended the fighting lines to homes and factories and churches and schools. It has brought death and injury to thousands upon thousands of noncombatants, has devastated cities and has destroyed irreplaceable monuments.

It is almost certain that the planes of the future will be far speedier and far more powerful than today's machines. They will represent a mighty force for good or ill; the choice will lie with man himself.

THE TRAVEL OF THE WATERS

The Plunging Sea Draws Backward from the Land Her Moon-led Waters White

THE TIDES AND CURRENTS OF THE SEA

THE sea bares her bosom not only to the moon but to the sun, not only to balmy breezes but to howling hurricanes, not only to summer zephyrs but to winter tempests, and accordingly the sea's temperature varies from place to place and from time to time. Yet, owing to the great capacity of water for heat, the surface temperature of the sea at any place is comparatively constant.

Between day and night, the average range of surface temperature is only one degree, and between summer and winter, unless there be seasonal variation in currents, there is a range of only 5 degrees to 10 degrees F. In the tropical zone the surface temperature of the sea never falls below 80° F. In the Red Sea it varies in its average summer and winter temperature by only about 10 degrees.

The temperature of the deep-sea water, though following other laws, is also very stationary. Deep water is always cold, even when the surface water is warm, except in an inclosed sea. At a depth of 300 or 400 fathoms, the water of uninclosed seas has a temperature of 40° F., or less. Five-sixths of the water of the oceans has a temperature below 40° F. The low temperature of the deep seas is due to currents of cold water from the polar regions. Even as there are currents of hot air flowing in the upper atmosphere from the equatorial toward the polar regions, and currents of cold air flowing in the lower atmosphere from the polar to the equatorial regions, so in the ocean there are cold currents flowing along the bottom of the sea from the polar to the equatorial, and warm currents flowing along the surface of the sea from the equatorial to the polar regions. In the southern hemisphere the cold water runs northward along the ocean floor without impediment; in the northern hemisphere the cold water has access only by narrow channels to the south, but in both cases there is a constant current of cold water along the ocean floor toward the equator.

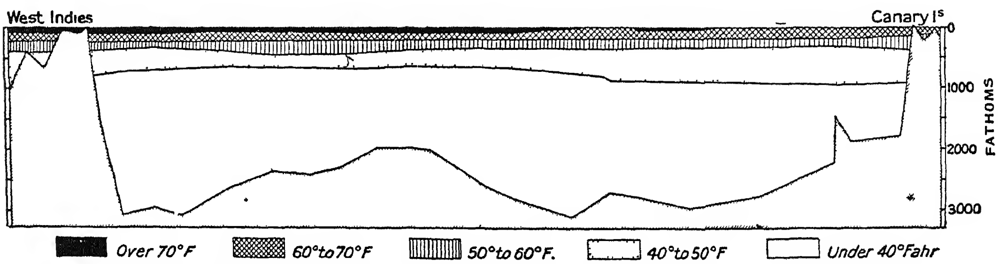
Bonney gives the following little simple experiment to illustrate the circulation of cold and hot water in the ocean:

"Take a small glass tank such as a common aquarium, and fill it with water. On the top of a piece of black rock, a few cubic inches in volume, sprinkle some cochineal, and put this close to one end of the tank, introducing it into the water so carefully and gently as not to disturb the coloring matter. Then fix a good convex lens in such a position that the rays of the sun are brought to a focus upon the piece of rock. At the same time place on the water at the opposite end a lump of ice, and upon this pour a small quantity of milk. As the rock is heated, the surrounding water, which is becoming stained by the cochineal, is warmed. It expands, and a red cloud mounts upwards. But at the other end of the tank the water, which is rendered slightly turbid by the milk, is chilled by contact with the floating ice, and so a whitish cloud sinks downwards. Presently the former begins to drift along the surface toward the ice, the latter along the bottom towards the heated rock, and thus a system of oceanic circulation is established."

In the case of inclosed seas, the cold currents are excluded, and so the bottom water keeps at a higher temperature The Red Sea, for instance, which on the surface has an average summer temperature of 85°, and an average winter temperature of 75° F., has a summer and winter temperature of 70° F. at a depth of 200 fathoms, and that temperature is maintained right down to its bottom The Indian Ocean, just outside, unprotected from cold currents, shows a temperature of 37° F. at the same depth

The constant circulation in the sea of cold, deep water from the poles to the equator, and of hot surface water from the equator to the poles, constitutes the "trades" and "anti-trades" of the sea But, besides these great voluminous circulatory currents, there are numerous other surface currents, mostly due, as has been said in a previous chapter, to wind. The wind pushes the surface water of the sea before it and by such wind-currents, nuts and beans and smaller seeds — flotsam and jetsam of all kinds — are carried from the West Indies to the shores of Iceland, or Ireland or Norway. The Great Labrador Current, driven by the northerly wind, brings icebergs to Newfoundland; and probably some contribution of stones and mud transported by the icebergs and deposited as they melt. The southeast trade wind blowing off-shore in the Bight of Panama produces the cool Peru Current, which, sweeping southward past the Galapagos Islands, gives them a more temperate climate than that of any other equatorial land. A cold current like the Great Labrador Current flows south through the Behring Straits.

The anti-trades of the Southern Ocean (in the so-called Roaring Forties) cause a great surface current in an easterly direction round the world A newspaper item of October 10, 1911, may be explained by aid of this current· "A life-buoy inscribed S. S *Waratah*, and covered with barnacles, has been found at Waiuku, on the west coast of New Zealand" The *Waratah* left Durban for Cape Town on July 26, 1909, but never reached her destination, and was supposed to have capsized in a storm The distance from Cape Town to the west coast of New Zealand is over 8000 miles, so that the life-buoy must have drifted eastwards at an average speed of nine or ten miles a day Probably it was the Roaring Forties that carried along this relic of the ill-fated ship.



A SECTION ACROSS THE ATLANTIC, SHOWING THE TEMPERATURE AT DIFFERENT DEPTHS

But the best-known current is that remarkable drift known as the Gulf Stream. The Gulf of Mexico is flooded with a current of warm water that sweeps into it from the South American coast through the Caribbean Sea. Out of the Gulf there issues, between the Peninsula of Florida on one side and Cuba and the Bahamas on the other, a mighty volume of blue, warm salt water — a great sea-river forty or fifty miles wide, about 200 fathoms deep, and flowing with a velocity of three and a half to five miles an hour The current has been calculated to contain more than two thousand times the quantity of water discharged by the Mississippi. Its temperature off Sandy Hook is 75° F. In the first place it flows northward close to the North American coast, but soon it comes into the clutches of the southwest winds, and is carried eastward across the Atlantic, spreading out and slackening its speed as

A SOUTH AMERICAN TIDAL WAVE

Photo Bippus

Photo Erbe

This tidal wave ("resaca") in July, 1921, broke with such force on the harbor front of Rio de Janeiro as to tear great holes in the wall and scatter the stones over the sidewalk and roadway behind it. The sea itself was but little agitated, but the spray was thrown to a height of 60 feet.

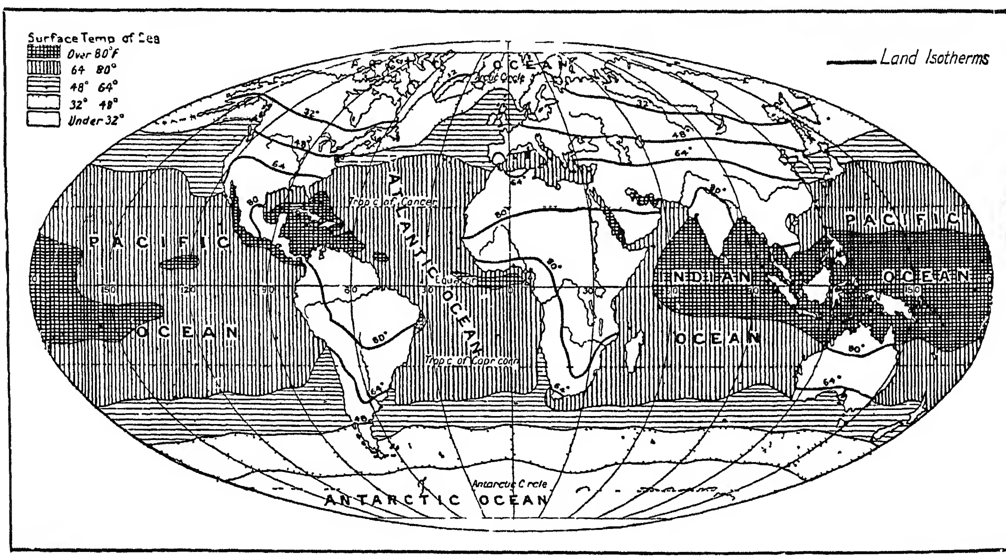
it proceeds. As it crosses the Atlantic, it divides into three currents, one going towards Iceland, one curving down past Spain, and one flowing past the west coast of Ireland and Scotland, and reaching even the west coast of Norway. The wind which brings this current is naturally warmed and moistened by it; and the warm, wet wind greatly modifies the climate of the lands it reaches, as we shall see when we come to speak of climate.

It has been estimated that the total quantity of heat transferred per day from the equatorial regions amounts to at least 20 per cent of the whole heat received from the sun by the entire area of the North Atlantic. The total heat of the current, if properly concentrated under conditions maintaining the due proportion between quantity and intensity, would suffice "to fuse mountains of iron and cause a river of metal as mighty as the Mississippi to flow forth. It would also suffice to raise from a winter to a constant summer temperature the whole column of air which rests on France and the British Isles."

Most of the currents are caused by winds, but perhaps it is a mistake to trace each current to a particular wind. Rather the ocean currents are a complex movement due to all the atmospheric currents and modified, like the winds, by the rotation of the earth, by the interference of land masses, and by other factors.

Besides currents caused by heat and cold and by wind, there are also currents caused through rapid evaporation of water, with consequent increase of saltness The Red Sea, for instance, is lowered at the rate of ten to twenty-five feet a year by evaporation, and the loss is replaced by a current of fresher water from the Indian Ocean; and at the same time a deep undercurrent of excessively salt water flows from the Red Sea to the Indian Ocean. The Mediterranean, similarly lowered by evaporation, receives a compensating current of fresh water from the Atlantic, and returns to the Atlantic an undercurrent of excessively salt water.

Currents are also caused by the reverse process by the excessive addition of fresh water, with dilution of the salt contents. Thus the Don, the Danube, and other great rivers pour so much fresh water into the Black Sea that it contains only 2 per cent of salts. As its surface stands about two feet higher than the Mediterranean the result is that a current of the diluted sea-water flows into the Mediterranean from the Black Sea, and an undercurrent of saltier water flows from the Mediterranean into the Black Sea.

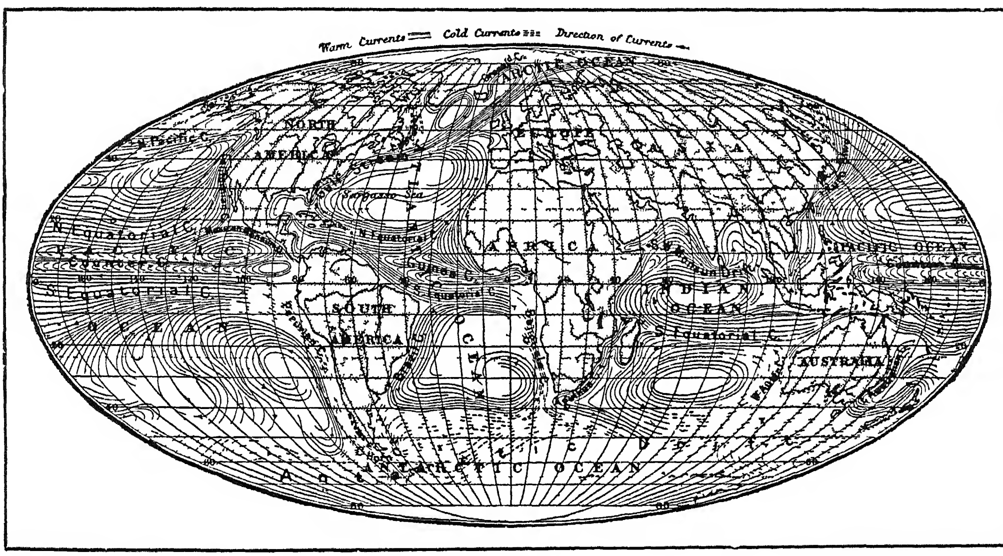


THE SURFACE TEMPERATURES OF THE OCEANS OF THE WORLD

Few natural phenomena make such an appeal to the imagination as the tides. Their surge and thunder bear witness to that mighty force that holds the earth and its sister planets in their orbits round the sun. The earth is tethered to the sun, and the moon to the earth, and all three are tugging at their tethers, but the hard crust of the earth hardly yields to the strain, and only the sea, pulled up into a great tidal bulge, as it passes under the moon, gives testimony to the tension. The silent earth, the tacit stars give no sign; but the surging tides testify to "the subtle, secret, unseen bonds that make a million systems one"

at twelve one day, when the sun is also in its zenith, it will reach its zenith next day fifty minutes behind the sun, and next day a hundred minutes behind the sun, and next day one hundred and fifty minutes behind the sun, till eventually, just when the moon has finished a course of twenty-eight days it falls back in line with the sun again, and both sun and moon are again in the zenith together. Once each lunar month sun and moon are in the zenith together, and between times they diverge to all degrees till at full moon the moon is exactly opposite the sun.

Now consider the effect of the relative positions of sun and moon. Theoretically



THE COURSE OF THE WARM AND COLD CURRENTS IN THE OCEANS OF THE WORLD

The uninformed person usually gives the moon the whole credit for the tides, but this is not correct; the sun also plays a part, and a not unimportant part, in the tidal excursions of the sea. The moon, however, has more than twice the tidal force of the sun; and so if they happen to pull to any degree against each other, it is the moon's tidal force that prevails. Let us look for a moment at the direction of the pull of sun and moon with reference to the tides and to each other.

The moon goes round the earth about once in twenty-eight days, and every day it is about fifty minutes later in rising. If, accordingly, the moon reaches its zenith

when the sun is right overhead in the zenith it is solar full tide, and likewise when the moon is right overhead in the zenith it is full lunar tide. Suppose, then, they both are in the zenith together, as occurs at new moon, then there will be full lunar tide and full solar tide together, and therefore we have a specially high tide. The high tide at new moon is known as a *spring* tide.

Suppose, next, that the moon is in its zenith when the sun is exactly opposite at the other side (such a position as occurs at full moon), then on the moon side of the earth we will have full lunar tide, which is also high tide, and is also a spring tide.

Suppose, finally, that the moon reaches its zenith when the sun is a quarter way round the world and therefore at right angles to it (such a position as occurs both at new half-moon and at old half-moon), then the pull of the sun will partly neutralize the pull of the moon, and we will have a lesser tide, known as a neap tide.

All this is pretty evident, but it may be asked how is it that there are two full tides in the twenty-four hours even when the moon and sun are not opposite each other? The reason simply is that each full lunar tide implies and necessitates a tide on the other side of the earth as well as on its own side. To understand this is not quite easy, but it is essentially a matter of differential attraction. The great law of gravitation enunciates the principle that bodies are attracted by other bodies in the inverse ratio of the square of their distance from each other. Thus a body A and a body B two miles from each other will mutually attract each other four times as strongly as if they were four miles apart, and a fourth as strongly as if they were one mile apart. That is the principle.

Now, the sea on the far side of the earth is 8000 miles further away from the moon than the sea on its near side, and further off, too, than the general globe of the earth, and therefore it is attracted less strongly, and, comparatively speaking, is left behind. Or we may put it in this way: when the moon is in its zenith and causes a full tide, it does so by drawing the sea on its own side of the earth towards it, but it draws not only the sea on its own side of the earth towards it; it draws also to a less extent the earth itself, while the sea on the other side, being farther away from the gravitative influence, is pulled to a less extent still, and so is left behind.

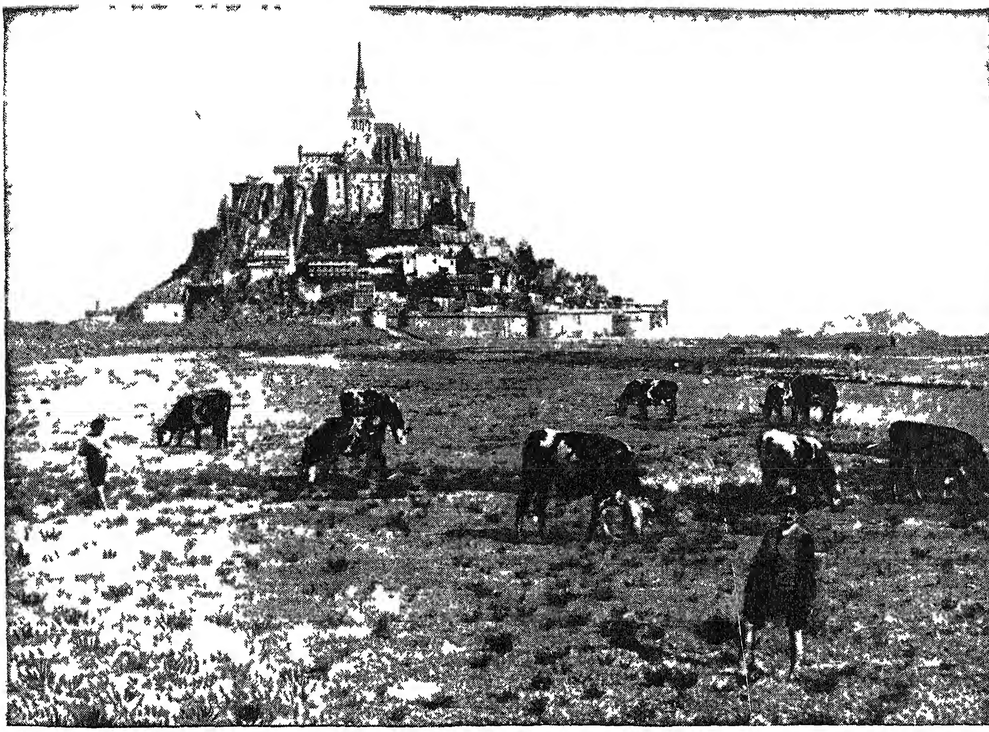
Theoretically speaking, spring tides should be at full moon and new moon, and full tide should be when the moon is at its zenith, but the tide seldom occurs in accordance with theory, chiefly because of the interference of the land. Only in the Pacific and Southern Ocean can the tide run along without interference; in all other parts of the world it is twisted and checked and diverted by land.

But even where high tide is not coincident with the meridian ascent of the full and new moon — *i.e.*, does not always occur at twelve o'clock — it always occurs with regularity; and if we know the time of full spring tide we can calculate subsequent tides The time that elapses between the moon's transit across the meridian at new or full moon and the period of high water at that place is called the "establishment of the port"; for New York this is 8 hours and 13 minutes. Since the tide, of course, flows progressively onward, the establishment of various ports in the line of flow is consecutive. Thus high tide at Yarmouth, N. S., is about 50 minutes earlier than at Digby, and 1 hour and 50 minutes earlier than at Truro. This interval between port and port depends on the establishment, and is, of course, constant.

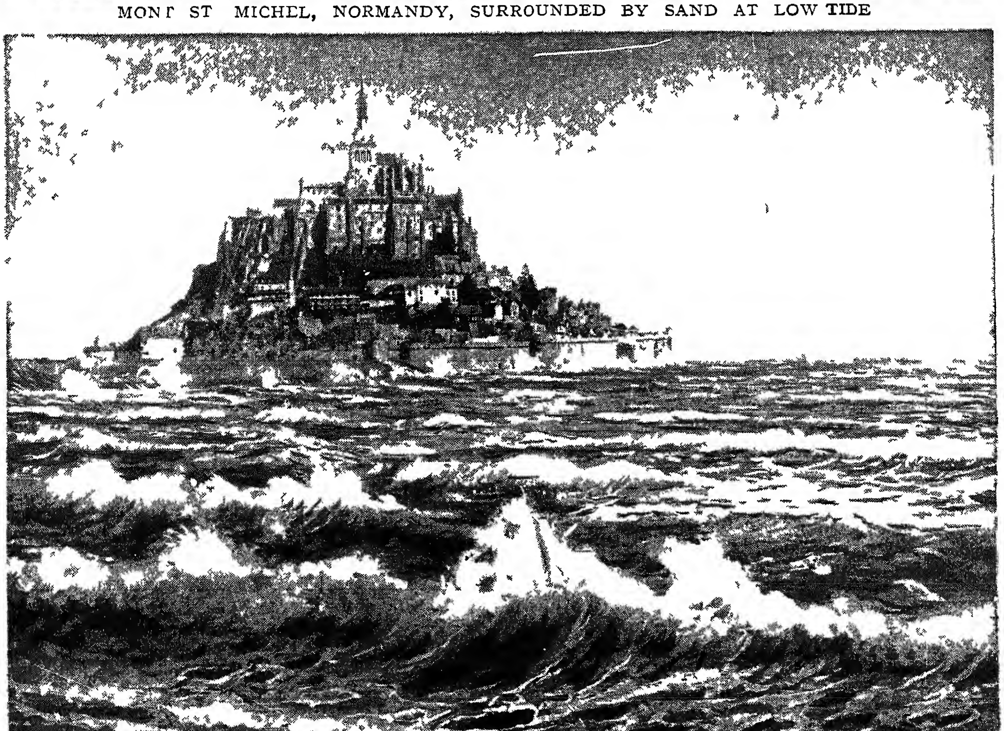
The extent of the rise and fall of the tides varies. In the open sea the tidal wave rises only two or three feet, but in narrow channels and bays the rise and fall may be very great. In some parts of the Persian Gulf and the China Sea the tides reach a height of 36 feet. In the Straits of Magellan, tides of 66 feet high have been measured; while at the top of the Bay of Fundy, in Nova Scotia, the maximum rise at spring tides is 70 feet.

In the Bay of St. Michel, on the northwestern coast of France, there is a magnificent tidal flow which produces transformation scenes twice a day. "At low water, the immense sandy plain, above one hundred and fifty miles in extent, resembles a bed of ashes, but when the tide, swifter than a horse at full gallop, rises foaming over the scarce perceptible slope, a few hours are sufficient to transform the whole bay into a sheet of grayish water, penetrating far up the mouths of the rivers as far as the quays of Avranches and Pontorson. At the ebb, the waters retire with the same speed to nearly six and a quarter miles from the shore, and lay bare the great desert strand, which is intersected by the subterranean deltas of tributary riverlets, forming here and there treacherous abysses of soft mud into which travellers are in danger of sinking."

WHERE THE TIDE GOES OUT FOR MILES



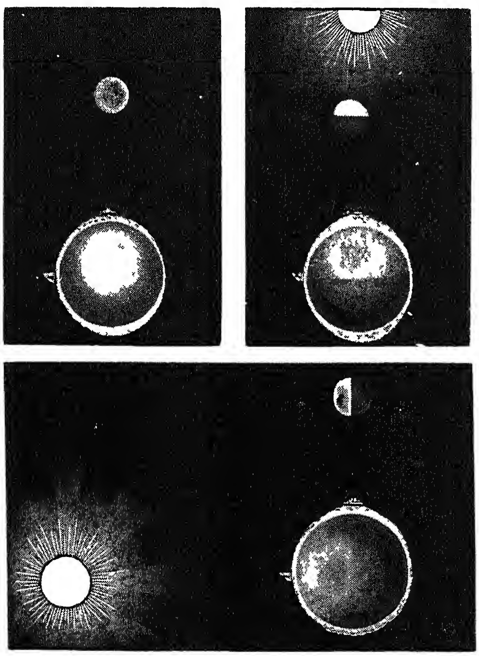
MONT ST MICHEL, NORMANDY, SURROUNDED BY SAND AT LOW TIDE



MONT ST MICHEL, NORMANDY, SURROUNDED BY THE HIGH SPRING TIDE
Photographs copyrighted by Underwood & Underwood N Y

In certain straits, very rapid and powerful currents or "races" are caused by the tides In New York harbor, for instance, in the narrow passage of Hell Gate between Long Island Sound and the East River, are such races, especially during ebb tide, also between Buzzards Bay and Vineyard Sound, between Cape La Hague and the island of Alderney and in many other places.

When currents meet they sometimes alternately prevail, giving rise to a to-and-fro movement. The so-called Maelstrom, to the south of the Lofoten Islands,



HOW THE TIDES ARE CAUSED
The two upper pictures show the spring tide when the moon is full and when it is new, the sun and moon pulling in opposite directions or together The lower picture shows how the neap tides occur when the sun and moon pull at right angles to each other.

is made in this manner, but it has not the whirling whirlpool motion ascribed to it by legend; it is merely a swaying current with lateral eddies. When the current flows fastest, between high and low tide, and meets a head wind, the sea for miles becomes so agitated that small vessels cannot live in it. Of similar nature are the currents in the Straits of Messina immortalized in the myth of Scylla and Charybdis, sea monsters personifying the dangers of navigation near rocks and eddies.

The incoming tide in the estuaries of rivers and in funnel-shaped bays causes a rapidly advancing wall of water, known as a "bore" The height increases as the bay narrows, and the wave is converted into a roaring mass of breakers, more pronounced the shallower the bay. The most remarkable example is the bore in the estuary of the Tsien-Tang-Kiang, in China. That of the Amazon reaches a height of 16 feet, and that of the Ganges nearly as much — but nearly all tidal rivers exhibit the phenomenon more or less.

In inland and inclosed seas tidal motion is very slight. In Lake Michigan the tide is only three inches in height, and in the Mediterranean and Baltic it is also only a matter of inches.

It is interesting to note the importance of the tides to commerce. Many of the great seaports — London, Hamburg, Havre, Montreal — have been built at the head of tide water, and were the moon to cease to draw up the tides it would mean ruin to their shipping trade. Venice exists by permission of the sea.

It is quite obvious that the tides — the motion backward and forward and upward and downward of great volumes of water — imply great mechanical power; and no doubt some day the difficulties of utilizing that power will be overcome.

There are other pulls on the sea besides the pull of the moon. Besides the fluctuating lunar tides, there are constant changes of level due to the pull of mountain masses. The sea surface is 300 feet nearer the center of the earth at Ceylon than at the Indus Delta, where the sea water is attracted by the mighty mass of the Himalayas; and it is estimated that the gravitative attraction of the Andes is sufficient to raise sea level on the west coast of South America 300 or 400 feet higher than sea level at the Hawaiian Islands. Even though the rocks of the sea bottom be denser than the rocks of the land, still that cannot quite counterbalance the mountains. And the sea level varies not only according to gravitative pull; it is also piled up by heavy rainfalls, and rivers, and currents, and it may be considerably depressed by rapid evaporation.

THE REVOLUTION OF MENDEL

The Monk who, Experimenting with the Growth of Peas in the Abbey Garden, Changed the Current of Scientific Thought

THE LIFE AND WORK OF A GREAT MONK

BY the irony of fate we now pass from the contributions to science of August Weismann, not to those of some junior contemporary, but to those of a man who died more than a generation ago, and whose work was done more than half a century ago. Yet that work is the foundation for the new era in the study of heredity which is characteristic of our own century, and which was initiated by its rediscovery in the first year of the twentieth century. It is high time, therefore, that we should acquaint ourselves, as closely as possible, with the name and life-work of Gregor Johann Mendel, who must be regarded as one of the epoch-makers in the science of life.

Some four decades have now passed by since the attention of the scientific world was directed to Mendel's long-standing and long-lost paper. The conclusions it contained were fiercely contested by the representatives of scientific orthodoxy at that time; and their authority was such that Mendel's law, as we shall learn to call it, was put down as a mere local phenomenon, a curiosity of certain cases of hybridism, and nothing more. Darwin was dead, and the general recognition of Mendelism was tragically delayed, even after the initial loss of a generation between Mendel's work and its discovery. But the logic of facts has conquered; and the establishment of the Balfour chair of genetics at Cambridge may be said to mark the final acceptance of Mendel's work by the academic world. We may therefore try to acquaint ourselves with what personal facts are available regarding one of the now acknowledged masters of science, and to this end we shall be greatly helped by the publications of Prof. William Bateson, one of the leading exponents of the Mendelian school, and the author of "Mendel's Principles of Heredity."

Gregor Johann Mendel was born, the son of a peasant, in Austrian Silesia, on July 22, 1822 Though the name suggests a Jewish origin, he was probably of German stock His father was interested in plants, and early taught his son the methods of fruit-grafting; and his mother's brother was an educational pioneer, so that there is some evidence of hereditary transmission on both sides in the making of the young Johann, as he was christened, Gregor being his name "in religion", taken when he was admitted to the Augustinian monastery at Brünn for the purpose of teaching under its auspices. In 1847 Mendel was ordained a priest, and later he was sent to the University of Vienna for two years at the expense of the cloister. Then he returned to Brünn, where he taught for fifteen years, especially science, for which his studies abroad had fitted him. He was a born teacher, and had extraordinary success with his pupils. At the end of this period, in 1868, he was elected abbot of the monastery.

Mendel loved teaching, and was not exhausted by it. He had energy enough left for the enjoyment of his interest in plants, and he had at his disposal the large garden of the cloister, where, even as a novice, he had begun experimental work, introducing various plants and watching their behavior under different kinds of treatment, and it was his pleasure to show these cultures to his friends.

How Mendel knew of Darwin, though Darwin did not know of his contemporary

While he was quietly working away under these conditions, for his own pleasure, and without thought of controversy or publication, or of the bearing of his observations upon anything so colossal as the theory of organic evolution, Darwin published the "Origin of Species" in London in 1859.

The whole world was at once filled with the noise of it. There was a Philosophical Society at Brünn, to which Mendel belonged, and thus, from the very first, he was acquainted with Darwin's name and work, whereas Darwin died without ever having heard of Mendel.

From the very first the latter was in disagreement with the fundamental theory of Darwin that species take their origin in the selection and perpetuation of minute random variations that are inherited by the offspring. Thus it is recorded that on one occasion, when showing his garden to a scientific friend, and noting how two species had been cultivated side by side for some years without showing any change, Mendel jokingly said: "This much I *do* see — that nature cannot get on further with species-making in *this* way. There must be something more behind." Indeed, it seems to have been the publication of Darwin's views that caused Mendel to persist in his experiments with peas, which he continued for a period of eight years. Nothing can now be more obvious than that what the Darwinian view immediately required was experiment in order to test it. Everything else — argument, theory, vituperation, controversy, reference to the observed facts of natural history — all these Darwinism received, but not experimental breeding. Mendel, however, the man of genius, saw instantly that that was what was required, and now we all agree with him. He communicated his results to the Brünn Society in 1865, 1866 and 1869, but they passed unheeded.

His cardinal work, as we already know, was done upon peas. But he also studied bees, a purpose for which the large monastery garden was very suitable. He actually had fifty hives under observation. On this part of his work Professor Bateson writes as follows: "He collected queens of all obtainable races — European, Egyptian and American — and effected numerous crosses between these races, though it is known that he had many failures. Attempts were made to induce the queens to mate in his room, which he netted in with gauze for the purpose, but it was too small or too dark, and these efforts were unsuccessful. We would give much to know what results he obtained. In view of their genetic peculiarities, a knowledge of heredity in bees would manifestly be of great value The notes which he made on these experiments cannot be found; and it is supposed that in his depression before his death they were destroyed."

An ecclesiastical promotion that impoverished the scientific world

This is a very serious loss to science. Years of faithful work, done by this highly gifted investigator, are wasted. The hives which he used still stand in their places, but the notebooks are gone. Very likely more than half of all the work he did is thus lost. But indeed, considering his opportunities and energies, and length of life, his total sum of scientific work was very small in bulk. The fatal day for science was that on which Mendel was elected abbot. There his researches ended. He himself hoped otherwise, expecting that after a time he would be able to do more scientific research than before. But, unfortunately, certain taxes were now imposed by the government on the property of religious houses, and these, which Mendel conceived to be unjust — and which were, in fact, removed a few years after his death — he refused to pay and continued to do so after other monasteries, with him at first, had given in. All his time was spent over this deplorable business and the legislation which it involved. Nothing would move him, even though the property of the monastery was ultimately distrained upon. He fell ill, and the last ten years of his life were passed in disappointment and bitterness, and he grew misanthropic and depressed. On January 6, 1884, two years after the death of Darwin, he died.

The strange neglect of the work of Mendel while he lived

All this time, of course, the controversy was raging over Darwinism. Far and away the worst result of all this litigation and diversion of Mendel from the special interests for which his mind was formed was that he never joined in the controversy, and never even wrote a letter to Darwin. The whole progress of biology, and the possibility of framing a true theory to explain organic evolution, have been delayed by decades in consequence. We are now only where our predecessors should have been many years ago. It seems not to be true, however, that Mendel had lost interest in his own researches, and did not care what happened to them. Apparently he had no time to do anything on his own account, and he was seriously disappointed that his work should have been neglected. He is reported to have believed in its future, as well he might, and to have been in the habit of saying: "My time will come!"

Why it did not come as and when it should have come will apparently be somewhat of a puzzle always. The history of science has many examples of cases where great discoveries have been despised, though there must be few, if any, "in which the discovery so long neglected was at once so significant, so simple, and withal so easy to verify". It seems to have been accident in this case, but it will always remain inexplicable that Mendel's work, appearing as it did when several naturalists of the first rank were occupied with these problems, should have passed wholly unnoticed, though we know that the Brünn Society exchanged its publications with most of the learned societies of Europe, including several of those of which Darwin himself was a member.

Mendel himself seems to have failed to interest one distinguished contemporary, and made no further attempts, though it would not have been Darwin's way to neglect new truths — the Darwin who had received Dr. Alfred Russel Wallace's paper from the other side of the world a few years before.

How Darwin's theories had lured men away from experimental research

Professor Bateson has doubtless put his finger upon the most profound cause of the neglect of Mendel's work for a generation. It was "that neglect of the experimental study of the problem of species which supervened on the general acceptance of the Darwinian doctrines". Until that time, many men were working on the species problem by experimental crossing, as Mendel did. But now new workers were not forthcoming, because Darwin's views had turned the attention of all biologists in other directions — the "struggle for existence", "natural selection", "adaptation", "spontaneous variations", etc. Also, Darwin strongly believed that "nature does nothing by jumps", and that the result of crossing could be totally left out of account in the problem of species formation. Thus the tedious methods of experimental breeding — which, further, were supposed to have yielded no definite results — fell out of fashion.

Unfortunate mistakes which partly neutralized the discoveries of great men

It was a very great pity, but it has its parallel in another branch of science. In the physical sciences Newton was, by universal consent, the greatest man who ever lived. Like all men, including the greatest, he made mistakes, the real value of a man not being measured against his mistakes, but by the quality and extent of his successes. Newton made great contributions to optics, above all in his discovery of the compound nature of white light by means of the prism. But he strongly advocated the "corpuscular theory" of light, according to which light consisted of a stream of separate particles, or corpuscles. It is the historical fact that this erroneous theory, having the authority of Newton's name, retarded the progress of optics for decades. And just similarly it now appears that Darwin's authority retarded for decades our knowledge of those fundamental facts of heredity upon which any true theory of the "origin of species" will some day depend.

Mendel's repudiation of the distinction made between varieties and species

So much for Mendel himself Let us now turn to his paper, "Experiments in Plant Hybridization", upon which his title to fame rests. "Hybrid" was used by Mendel for the offspring of two varieties, though the term is often restricted to the offspring of two distinct *species*. He himself held that this difference between varieties and species is only a question of degree, and he was quite content, therefore, to use the term "hybrid" for the offspring of two varieties, and to speak of his experiments as "hybridization". Unfortunately, when his work was rediscovered, many critics argued as if it dealt with the crossing of distinct species, producing such hybrids, in the stricter sense, as the mule; and as such hybrids are commonly sterile, though that view must now be qualified, it was argued that the Mendelian observations could have no bearing on the formation of new species. We here note, then, that in point of fact his work was done with varieties of a single species, though he happens to call it "hybridization", and that today we are bound, by his own work and that of his followers, to agree with him that the distinction between varieties and species is not even a real one in any case.

In his preliminary remarks the author writes as follows:

"Those who survey the work done in this department will arrive at the conviction that, among all the numerous experiments made, not one has been carried out to such an extent and in such a way as to make it possible to determine the number of different forms under which the offspring of hybrids appear, or to arrange these forms with certainty according to their separate generations, or definitely to ascertain their statistical relations. It requires, indeed, some courage to undertake a labor of such far-reaching extent; this appears, however, to be the only right way by which we can finally reach the solution of a question the importance of which cannot be over-estimated in connection with the history of the evolution of organic forms. The paper now presented records the results of such a detailed experiment This experiment was practically confined to a small plant group, and is now, after eight years' pursuit, concluded in all essentials"

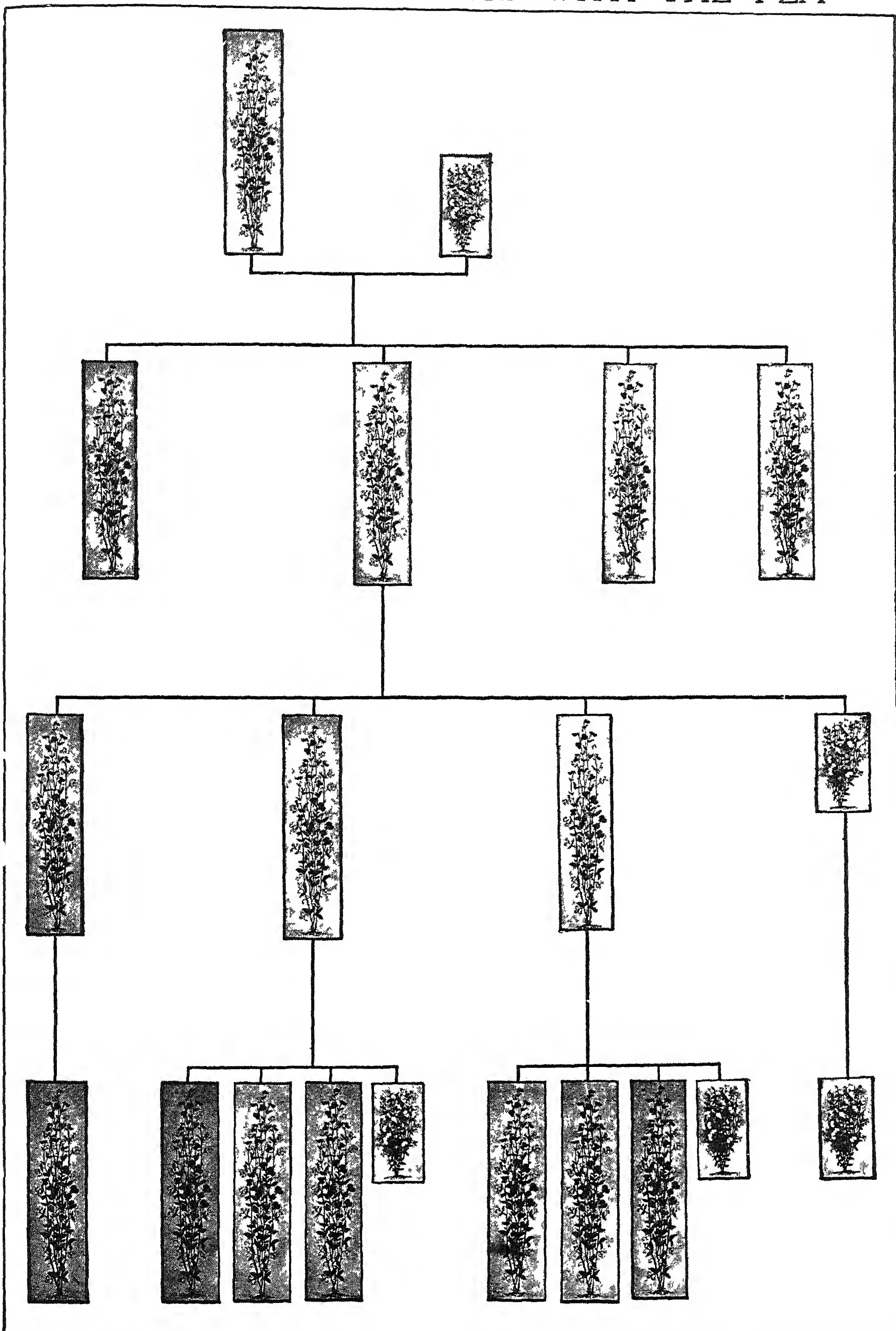
Of course, the facts had been waiting for ages to be ascertained; but though they would certainly reveal themselves automatically on certain conditions, they could never be recognized otherwise.

Mendel's proof that a study of only two generations is practically of no account

Mendel realized those conditions clearly, as none of his predecessors did, and they were the condition of his success. He describes them in the foregoing passage The three primary necessities were to discover the number of forms under which the offspring of hybrids appear, to keep the successive generations sharply distinct, and to discover the numerical proportions between the various forms obtained. Many of Mendel's predecessors had performed hybridization experiments, observing what forms the hybrids took when different species or varieties were crossed We now see, after the event, what Mendel saw before it — that such experiments have only been begun, and that we can reach no conclusions from them until we have mated the hybrids among themselves, and have determined "the number of different forms under which the *offspring of hybrids* appear". Thus, if Mendel showed anything, it was that our study of heredity can never be brought to true conclusions by means of observations or experiments upon two successive generations alone. At the very least, we must have three generations to compare; and all the statistical and other work on heredity, before Mendel's time and since, which only compares parents and offspring, has to be left finally on one side. It can teach us nothing.

The plant which Mendel chose for his observations was the ordinary edible pea, *Pisum sativum*. He chose it because its varieties are sharply marked in various definite respects, and because it was possible to protect the hybrids, during their flowering period, from the influence of all foreign pollen.

MENDEL'S EXPERIMENTS WITH THE PEA



A PICTURE DIAGRAM OF THE RESULTS OF CROSSING TALL PEAS WITH DWARF PEAS

This is of cardinal importance; and neglect of it has prevented the revelation of Mendel's law in many experiments made before his day and after it, for, as he said: "Accidental impregnation by foreign pollen, if it occurred during the experiments, and were not recognized, would lead to entirely erroneous conclusions."

Mendel studied thirty-four more or less distinct varieties of peas, with regard to the hereditary transmission of a number of characters, such as the form of the seeds, their color, the position of the flowers, and also the length of the stem. This last was particularly striking, for it was possible to cross plants with a stem of six to seven feet with dwarf plants averaging only one foot high. In all, he studied seven distinct characters; and the first result he obtained, in each case, was one which hybridization experiments had frequently shown before. This result was the absence of what is sometimes called "blended inheritance". It seems reasonable to suppose, for instance, that the hybrid offspring of two plants, one six feet and the other one foot high, would "strike an average" between the parents. But this never happened; the offspring of these crosses were always as tall as the tall parent. We shall see in due course what happened to *their* offspring.

Mendel's argument that blended inheritance really does not happen

Meanwhile, we note this initial fact, a cardinal idea of Mendelism, that so-called "blended inheritance" really does not happen. We may often see, in human beings and elsewhere, what looks like blended inheritance, and the assumption by the offspring of a sort of compromise between two markedly different parents. But probably every one of these cases is due to faulty analysis on our part. Either we are confounding mere fluctuations, due to varying nurture, with natural, hereditary, genetic characters, as the biometricians did, or else we are dealing with characteristics due to a great number of different factors, all intertangled, of which we are not yet able to trace the transmission separately.

Now, in all Mendel's experiments, one of the pair of contrasted characters represented in the individuals he was crossing appeared in *all* the offspring, while the opposite disappeared. Hence his new terms, introduced by himself as follows: "Henceforth in this paper those characters which are transmitted entire . . . and therefore in themselves constitute the characters of the hybrid, are termed the *dominant*, and those which become latent in the process *recessive*. The expression 'recessive' has been chosen because the characters thereby designated withdraw or entirely disappear in the hybrids, but nevertheless reappear unchanged in their progeny, as will be demonstrated later on. It was furthermore demonstrated by the whole of the experiments that it is perfectly immaterial whether the dominant character belong to the seed-bearer or to the pollen-parent; the form of the hybrid remains identical in both cases."

Mendel's theory of the grouping of hybrid characters into dominant and recessive

The generation of hybrids thus described is known as the first filial generation, or, in the modern terminology of genetics, the F 1 generation. Its characteristics establish the idea of dominance and recessiveness, of which we shall hear so much hereafter. From a literary point of view it is, perhaps, to be regretted that the words employed by Mendel were not *dominant* and *recedent*, or we might speak of them as *patent* and *latent*. But it is to be observed that we have no right to speak of the character which does not appear as recessive or latent, so long as we study only the F 1 generation. So far as that generation is concerned, the shortness, for instance, of the short parent is simply not transmitted; there is no sign of it in any of the offspring. How many acres of waste-paper must we regret, filled with calculations and assertions as to, say, the non-transmission of such and such a character, on the ground that the offspring of the parent that displayed it are found to show no trace of it at all!

Only when the individual hybrids of the F 1 generation are bred from, do we discover the truth, which is that the characters of which no vestige appeared in the F 1 generation were not, therefore, necessarily lost. For in the F 2 generation — *i.e.*, in the offspring of the hybrids — the recessive characters reappear. Here is the memorable paragraph from Mendel's own paper, in which his epoch-making discovery is stated: "In this generation there reappear, together with the dominant characters, also the recessive ones with their peculiarities fully developed, and this occurs in the definitely expressed average proportion of three to one, so that among each four plants of this generation three display the dominant character and one the recessive. This relates, without exception, to all the characters which were investigated in the experiments. The angular wrinkled form of the seed, the green color of the albumen, the white color of the seed-coats and the flowers, the constrictions of the pods, the yellow color of the unripe pod, of the stalk, of the calyx, and of the leaf venation, the umbel-like form of the inflorescence, and the dwarfed stem, all reappear in the numerical proportions given, without any essential alteration. *Transitional forms were not observed in any experiment.*"

The curious results in the second generation of Mendel's crossings

That was an unheard-of result to obtain. The tall and the short, for instance, when crossed, yielded an F 1 generation all tall. But *their* offspring persistently came out in the ratio of three talls to one short, still further disposing of the view that inheritance is blended. It was evident, on the contrary, that something which involved tallness, and something which involved shortness, could go into a new individual, or fail to go, or even that both might go, as in the hybrids of the F 1 generation; yet they did not blend with each other even then, but separated or "segregated" again, as was proved by the tallness or shortness of the individuals of the F 2 generation, who were just as sharply contrasted as their grandparents had been.

Now, the student must be patient, for this is not all, and the mind is very apt to become confused. This definite ratio of, for instance, three talls to one short in the F 2 generation must mean something; and Mendel naturally had recourse to what we now recognize as the one method of finding out the real structure of individuals. He bred from them, with most notable results. The shorts remained short in their offspring, and in theirs and theirs indefinitely. Evidently the tallness had been bred out of them, notwithstanding their parentage. Thus, we observe, in such a case it was possible at once to extract a short race, which bred true, from tall parents. This would be a mystery indeed did we not know what the parentage of those tall parents had been.

The effects brought out in a third generation by crossings

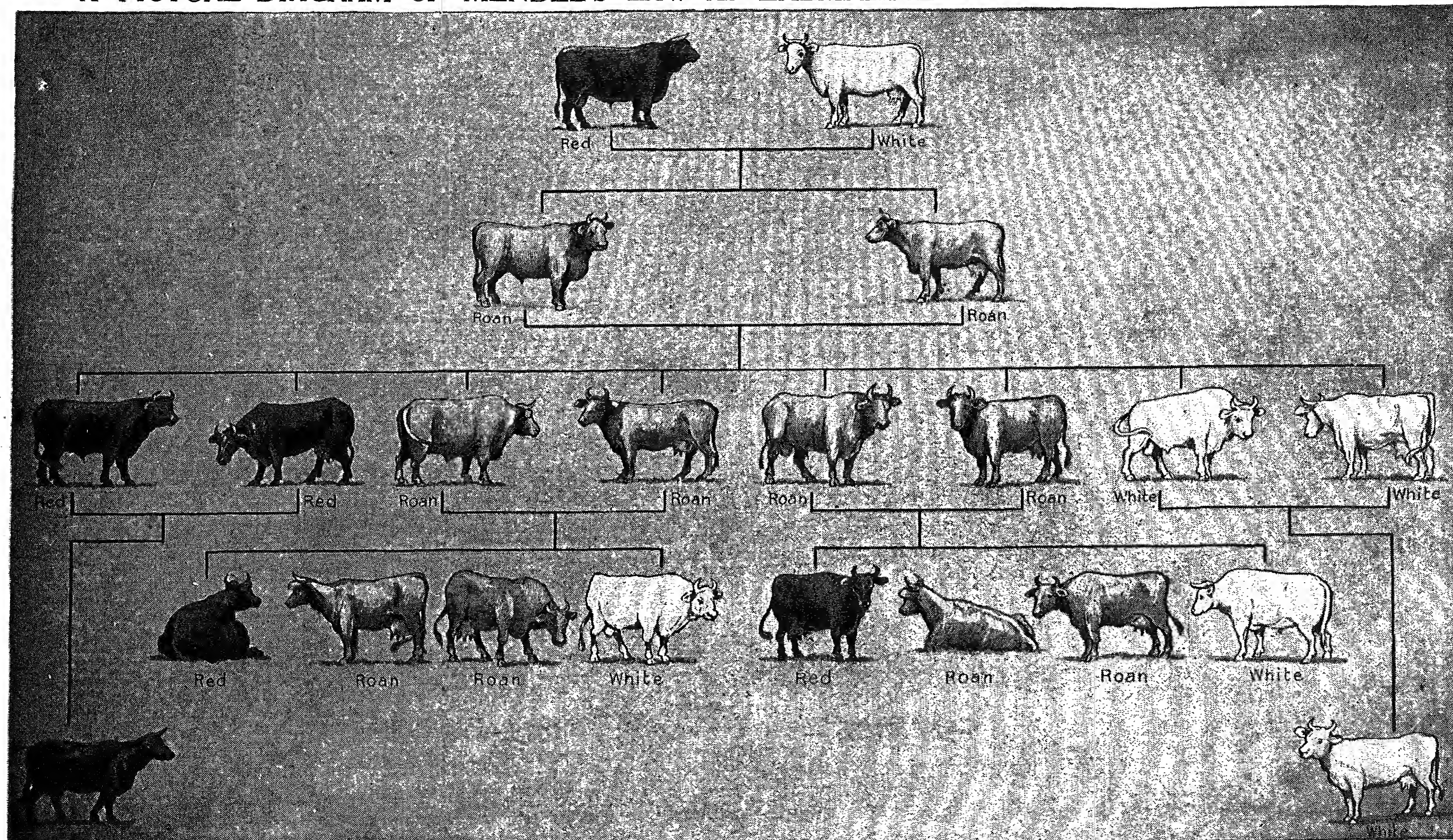
But now consider the three-fourths of the F 2 generation which were tall. All alike possessed the dominant character, which was seen in their parents, and in one of their grandparents. But when they are analyzed, by the unique Mendelian method, which is that of breeding from them, it is found that they are not really all alike in their genetic constitution. One-third of them yield talls, and those talls yield only talls, and so on. This third of the tall three-fourths thus compare and contrast with the remaining fourth, which were short. In each of these fourths of the F 2 generation the hybrid character has been completely separated, so that the one-fourth is purely tall and will yield nothing but talls forever, while the other fourth is purely short.

As for the remaining two-thirds of the three-fourths that were tall, they are just like their hybrid parents, and their offspring come out again in the ratio of three talls to one short, just as before.

The result showing that variation depends on composition of the germ-cells

What this all means we must let Mendel himself state: "It is now clear that the hybrids form seeds having one or other of the two differentiating characters, and of

A PICTURE-DIAGRAM OF MENDEL'S LAW AS EXEMPLIFIED IN THE COLORS OF CATTLE



If pure red and pure white cattle whose colors are of equal potency are bred together, the results shown in the above picture may be expected in the subsequent generations. The Mendelian explanation is that the roan hybrid carries from the beginning all the sex-cells which will decide the color, and carries them in a pure and not a blended condition, these cells being produced in approximately equal proportions.

these one-half develop again the hybrid form, while the other half yield plants which remain constant and receive the dominant or the recessive characters (respectively) in equal numbers." Later on, he states the same conclusion in slightly different words: "The offspring of the hybrids of each pair of differentiating characters are, one-half, hybrid again, while the other half are constant in equal proportions, having the characters of the seed and pollen parents respectively."

Any reader who has not previously studied the results of Mendel will probably be content at this point that we should not follow the complications which ensue when we observe various combinations of characters, instead of simply studying contrasted pairs, one at a time. But already the results, as stated above, suffice for a conclusion. These ratios, their definite character, and their definite behavior in successive generations, must clearly depend upon the composition of the germ-cells, or gametes, as we now call them, which are formed in the various types of individuals that we have studied.

Mendel's conclusion about the production of constant forms from hybrid plants

Thus, when Mendel had described in detail all the results of his experiments, of which the essential part has been given above, he proceeded to the concluding portion of this wonderful paper: "The Reproductive Cells of the Hybrids." He says: "So far as experience goes, we find it in every case confirmed that constant progeny can only be formed when the egg-cells and the fertilizing pollen are of like character, so that both are provided with the material for making quite similar individuals, as is the case with the normal fertilization of pure species. We must therefore regard it as certain that exactly similar factors must be at work also in the production of the constant forms from the hybrid plants. . . . The conclusion appears logical that in the ovaries of the hybrids there are formed *as many sorts* of egg-cells, and in the anthers *as many sorts* of pollen-cells, as there are possible combination forms."

A summary of Mendel's essential ideas that preceded Weismann

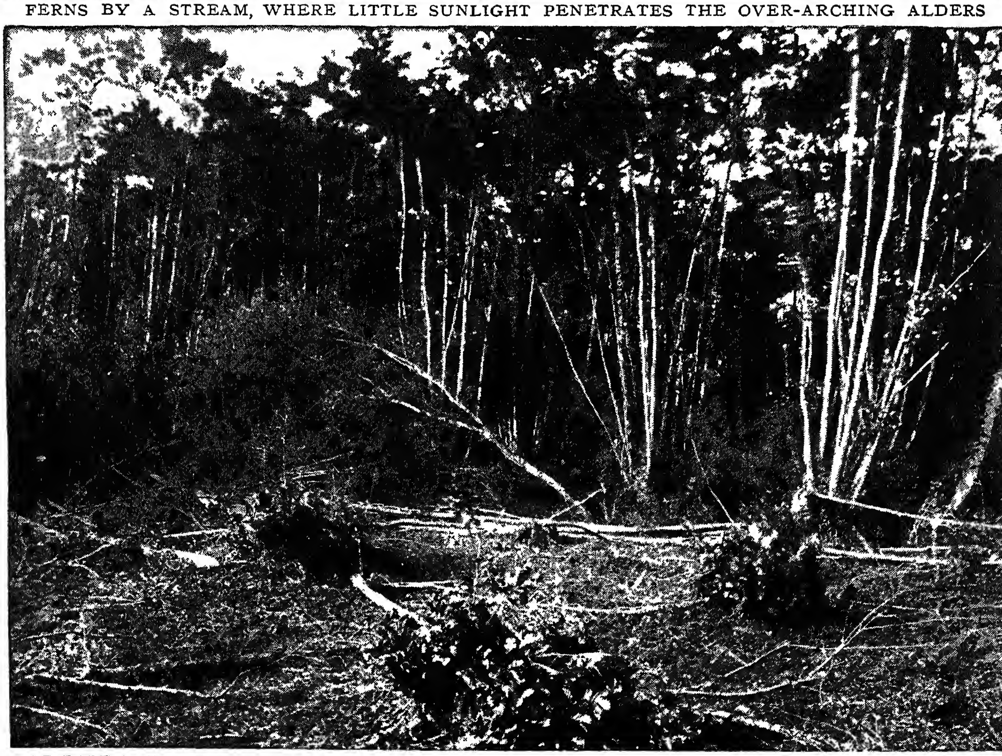
And thus the characters and the proportions of the individuals formed in successive generations, as we have seen, can be completely accounted for "if we assume that the various kinds of egg and pollen cells were formed in the hybrids on the average in equal numbers". And here, finally, is the paragraph which ends the paper and contains Mendel's law of segregation: "The law of combination of different characters which governs the development of the hybrids finds, therefore, its explanation and foundation in the principle enunciated, that the hybrids produce egg-cells and pollen-cells which in equal numbers represent all constant forms which result from the combinations of the characters brought together in fertilization."

These excerpts from Mendel's paper contain the essential ideas (enunciated long before Weismann's theory of determinants, which we have already studied), first, that the characteristics of the individual are due to some kind of entities, "factors" or "determinants", existing in the germ-cells from which the individual is developed; second, that these factors are distributed in the germ-cells according to the laws of chance; third, that opposite factors, meeting in a germ-cell, would not blend, but segregate; and fourth, that when opposite factors meet, one tends to be dominant and the other recessive. As to the interpretation of this last fact we shall see later.

Here, however, we may leave Mendel and his work. But for the inclusion of his name in a bibliographical list, which ultimately led to the rediscovery of his paper, the records and controversies of science were silent about him until he had been dead for sixteen years. Then, in 1900, thirty-five years after his work was completed, there appeared independently, but within a few weeks of each other, the three papers of the botanists De Vries, Correns and Tschermak, each of whom confirmed and extended Mendel's conclusions. With that date begins the modern era in the study of heredity.

PLANTS THAT DIE IN FULL SUNLIGHT

FERNS BY A STREAM, WHERE LITTLE SUNLIGHT PENETRATES THE OVER-ARCHING ALDERS



THE BARE PATCH IN A WOOD WHERE TREES HAVE BEEN FELLED FOR A YEAR, WITH THE RESULTANT DEATH OF THE SHADE-LOVING UNDERGROWTH THAT FLOURISHED LUXURIANTLY

The photographs on these pages are by Messrs Hinkins & Son and Mr. J J Ward

A PLANT'S FIGHT FOR LIFE

Some of the Special Arrangements by which Accommodation to Changing Circumstances is Secured

THE EXTERNAL RELATIONS OF PLANTS

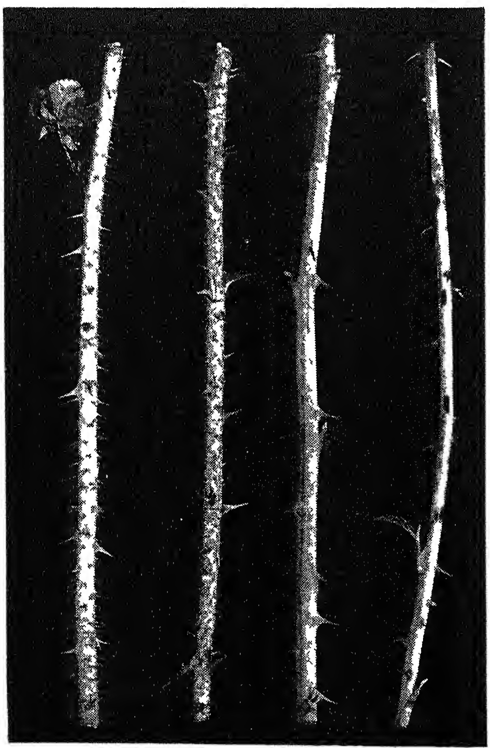
THE physiology of plant life, which we have now under discussion, embraces a very great number of processes, all devised to render the success of the plant more probable, and some of these processes are of a very complicated nature. We have studied in a general manner what may be termed the primary physiological processes upon which the very existence of the plant depends. That is to say, we have paid some attention to the nature of seeds and their germination; the production of roots, and stems, and leaves; and the necessity for obtaining from the soil and the air such substances and elements as are needed for the manufacture of protoplasm. But in all these cases, up to the present, we have been assuming that the plant has no special difficulty to overcome in carrying out its functions, and we have therefore had no occasion to study any special arrangements which may be required in the face of special difficulties.

It can be readily understood that in the infinite variety of the species of plants and trees which constitute the flora of any country, the struggle for existence and survival must be an extremely acute one in natural conditions. It is not surprising, therefore, to find that an enormous number of very special adaptations to environment are to be found in connection with plants. It is to the more detailed study of these special arrangements that we must now devote some little attention.

The problem is how the plant may best adapt itself to its external relations in so far as they are of such a nature as to demand the making of some special provision. They are those especially which have reference to the amount of available water or moisture surrounding it; the presence or absence of sunlight, and the effort necessary to obtain such little as there may be; the peculiar character of the soil in which the plant happens to find itself, and which may not be all that is most desirable for that particular species; the special constitution of atmosphere in the locality; and other factors of a similar nature. Then, too, there is the great question of the protection of the plant from the destructive tendencies of animals, and the efforts which plants must make in order to survive a time of drought and so forth. All these are what we may term the "external relations" of plant life, the factors in the environment in connection with which the plant or the tree is to make its effort for survival; and their mere enumeration suffices to indicate that there will be an immense variety of circumstances, or combination of circumstances, in the presence of which, unless plants evolve some special arrangements for their own safety, survival would be impossible.

In our last chapter we studied the structure and functions of leaves, and some of their movements. We may therefore first of all turn our attention to the arrangements made by which leaves are so exposed to sunshine and air that they may best carry out their functions. The reader is urged to examine for himself the arrangement of the leaves on a considerable number of trees and other plants, some of which we shall mention. Such examination will reveal the necessity of the adaptation to external relations we are now considering.

In the case of such native trees as the beech, elm, oak, apple and chestnut there may be shoots that are primarily vertical while others are primarily horizontal. To secure a maximum amount of sunlight, the leaves are arranged on the vertical shoots in spirals so that any given leaf does not shade the leaf next below it on the shoot. Though the buds on a horizontal shoot of these trees may be arranged spirally, the leaves commonly arrange themselves alternately in a common plane on either side of the shoot (see page 2341).



William G Smith, Jr.

Wild-rose (left) and bramble (right) stems, showing nature's arrangement for climbing and defense.

In many trees that have their leaves placed opposite to each other, each pair occupies the space between the pair immediately below, as may be seen if one looks down on a shoot of the horse chestnut. Similar very perfect arrangements will be noted in many of our climbers. The arrangement of the leaves in the horse chestnut, when examined at the end of a shoot and vertically, has been termed a leaf mosaic, on account of the variegated pattern that the leaves of this fine tree present.

The fringelike division of leaves serves a similar purpose

Another device for a similar purpose, which is found in many plants, is the fringelike dividing of the leaf, as in that of the carrot. Such a leaf, while it will obtain as much sunlight as possible, does not shade to any great extent the leaves below it Moreover, it is in less danger from strong winds.

We saw in another chapter that the green coloring matter in plants, in the presence of sunlight, plays a very important part in the physiology of a plant. But it must have occurred to some readers that there are numerous plants that have no chlorophyll at all, and live in various situations where light never penetrates. Many of these plants belong to the group of fungi, and subsist upon the organic matter, produced by animals or other plants, that may be found wherever these fungi flourish. Rains washing into these underground nooks and crannies may be one of the agencies responsible for getting organic matter into these places.

Wherever light penetrates, plants are usually of a green color

When we examine the plants growing in caves and underground mines, or in pits and wells, where there is a certain amount of light penetration — even if very little — we find that the plants are principally of a green character. Not only is this so, but the green coloring of vegetation within caves is often luxuriously brilliant and may appear even more vivid than that of an ordinary plant in the open air. Examples of this fact may be observed in the liverworts and in many of the mosses and some of the ferns that flourish abundantly in these situations. In such cases the chlorophyll granules are developed in a very special way. The light falling upon the plant cells is concentrated on the chlorophyll granules themselves, which thus receive a sufficient supply for their special functions, so very important to the plant.

There is another situation in which plants receive a minimum amount of light, namely, in the depths of the sea or at the bottom of lakes and ponds, where the sun cannot reach them. The light under water diminishes in proportion to the depth and is greatly influenced by the amount of sediment in suspension and so varies before and after storms and at different distances from the mouths of rivers and streams. Two hundred meters below the surface of clear sea water (about 600 feet) it is completely dark. At a depth of 170 meters, the illumination is about equal to that at the surface of the water during moonlight; and this degree is not sufficient to enable plants possessing chlorophyll to manufacture the complex substances we studied in our last chapter as being formed in ordinary green plants in sunlight. The greatest depth at which the chlorophyll cells can decompose carbonic acid is 70 meters, and at this depth the process can only be carried on in clear, transparent water during bright sunshine. Such combinations at such a depth are, of course, uncommon, especially as the plants may be growing on a sloping surface, and so receive the light at an angle; and, as a matter of fact, plants possessing green coloring-matter are rarely met with at a depth of more than 60 meters. The vegetation of the sea, speaking generally, is found within some 30 meters of the surface, so that we may regard the ocean depths as devoid of plants as we know them.

It must also be remembered, in connection with the sea, that plants living therein are surrounded by blue light, and the more salt the water the deeper is the blue. Therefore, the conditions are very unfavorable for growth at great depths, especially as the particular rays of light which the chlorophyll requires (the red, yellow and orange rays) are abstracted as the light passes through. On this account a very simple yet remarkable adaptation has been evolved by plants that find themselves in these conditions. Instead of the green coloring-matter, we find a red pigment, in addition to, or in excess of, the green. It can absorb a large quantity of the light falling upon it, and, moreover, the blue rays are changed by it to those rays which act upon chlorophyll. As Kerner says: "Green has given place to red. Sometimes a delicate carmine, sometimes a deep purple; then again a light brownish

HORIZONTAL TWIG OF A CHESTNUT
Showing leaves in a common plant

red and a dull, dark crimson; and as we admire in the bush the innumerable gradations of green color, so is the eye delighted in the manifold shades of red in which the different variegated species of Florideæ, intermixing with one another, display themselves."

THE ARRANGEMENT OF THE LEAVES OF THE CARROT

If we now turn our attention to the flora found on the rocky slopes just above the sea level, but still exposed to the spray in wild weather, we might expect to find — considering we are in the presence of di-

rect sunshine — that the plants would now be of the usual green. Instead of that, they frequently exhibit foliage of a gray color with leaves and stems covered with white hairs, the whole being matted together. Another marvelous adaptation to external conditions is here, and one which has been rendered necessary for precisely the opposite reason to that which we saw in the great depths. There the light was deficient; here the surface of the rocks is too glaring. In both cases the chlorophyll granules must be modified in some way to meet the exceptional situation. Too much light may be just as harmful as too little; and so these plants on the sun-exposed rock have evolved a special covering of a silky or woolly nature

MOSS, THE CARPET OF THE SHADY WOODS

by means of which they are protected from the too brilliant light.

This injurious effect of brilliant sunshine upon some of our most beautiful green plants is a point that should be carefully noted. An excellent example of it may be seen when a clearing is made in what was before a dense portion of a wood, and, as the result, the leaves of the trees, that formed a protection to the undergrowth, are removed. Within a week or two the delicate plants and ferns of vivid green of the exquisite floor under the shaded trees have withered. In this case we are face to face with an inability on the part of these plants to adapt themselves to the new conditions, and the flood of light thus thrown upon them coupled possibly with changed humidity of air and soil is an actual cause of death.

Next we may note that special protective arrangements are found in connection with plants that live the whole of their active life in climates or circumstances where the full power of the sun is felt from its rising to its setting. To avoid injury from this excess of light, certain structures of a hairy character may be developed and cover the surface of the leaf, giving the latter a grayish or whitish tinge. If they be removed, the leaf underneath is found to be normally green. So here we have a sort of awning erected to shade the chlorophyll from excessive light. No wonder, therefore, that these hairy, silky, or woolly growths are widely found among plants.

Another arrangement devoted to a similar purpose is that of the production of blue coloring-matter in leaves and stems much exposed to light. We find a similar thing in the leaves and stems of Alpine plants grown in the heights where sunlight is extremely powerful. These structures are of a dark violet color. All these adaptations are examples for the protection of chlorophyll — adaptations to external relationships.

The position of the leaf surface itself, with regard to the direction of the rays of the sun, is also a matter of great importance. The rays that fall upon a vertical leaf surface at morning and evening have just the required intensity for the functioning of chlorophyll. So we do not so commonly find such leaves in the dark, shaded spots. The iris does not grow in a dense wood, but on the ridge of a mountain or an open plain; and should it be planted in a shaded locality, the leaf surface does not adopt the vertical attitude, but turns until its broad surface faces a diffused light. Should the light come from above, the leaf may even assume the horizontal position.

A cursory examination of the small plants growing under large shady bushes — indeed, of all the plants that grow under the shadow of larger ones — will show similar adaptations for the reception of sunlight. The two kinds of plants exhibit no sort of mercy to each other. They struggle to exist, one against the other.

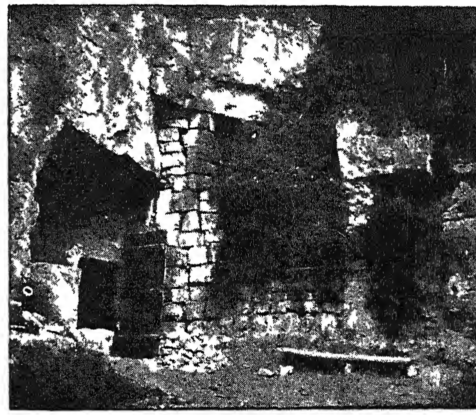
It is only when we come to the single plant that we find evidence of the adaptive change which is evolution. That is to say, it is the different parts of the plant itself which are concerned in helping the whole individual to survive. Hence we find that in connection with the leaves they must be so arranged that one does not take the light from the next; must not injure its next neighbor when it turns, must not secure all the exposure, and so forth. But it must so adapt itself — as if by actual foresight — that the different members of the same corporate body so cooperate that the whole is benefited.

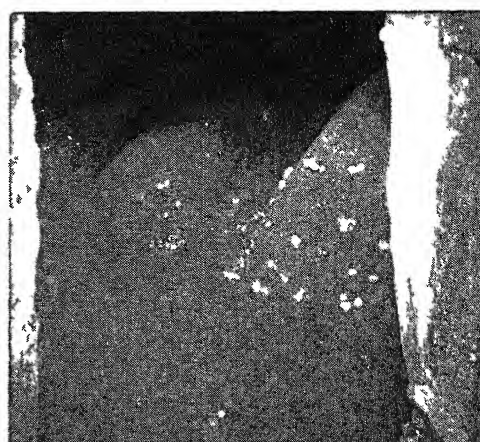
Quite a number of special forms of adaptation to environment may be studied in connection with water-plants, or hydrophytes, that live their entire life in a medium of water and die when exposed to the air. Such plants very frequently exhibit quite special methods of reproduction. Thus they may show the formation of special embryonic cells, which for a time live a free life, swimming here and there in the water, until they either find, or are deposited in, some spot suitable for growth, when they adapt themselves, and for the rest of their life remain fixed.

When submerged plants are free from attachment, they are found to be living in practically still water, such as that of ponds; and these plants may have no roots at all, for the simple reason that they have no use for them. Moreover, they may pass part of their life at the bottom of the pond, and another part at the top, producing during the latter phase new leaves, and perhaps even flowers, sinking once more to the bottom when this stage is over. Examples of this mode of life are found in Stratiotes, a plant which is too common in England and a relative of our eel-grass, Vallisneria.

The majority of hydrophytes, however, are attached to some fixed point. But a very interesting difference is to be noticed here as a comparison with that which obtains in ordinary land-plants. The attachment of a land-plant by its root serves to fix the plant in position, but it also serves the still more important function of abstracting nourishment from the soil at the point of attachment. In some water-plants, like the large seaweeds, however, there is no such nutritive function carried on at the point of attachment; and hence the composition of the material to which the plant is attached is a matter of comparative indifference.

The food of such water-plants is absorbed from the water in which they live





PLANTS THAT GROW IN DARKNESS

In the lower picture are shown mushrooms which grow in a covered stone-quarry, the door of which is shown in the upper picture

through practically the whole of their surface, and therefore there is no occasion for the development of some of the very special structures we have studied in land-plants. Root-hairs are not required, neither are the stomata which we have studied in connection with leaves, and which are so important in ordinary plant physiology.

Moreover, the nutrition of such seaweeds is diffused throughout the whole of the medium in which the plant lies — namely, the water — and therefore there is no occasion for any search on the part of the plant for food in the surroundings. It further follows that special organs for such a search are not required. Nearly all water has some form or other of currents in it, or is changed and renewed in different ways, and so keeps up a constant supply which the plant may use. Here, then, we have comparatively simple structures for absorptive purposes in response to the plant's adaptation to external relationships.

The water-lily, like the kelp, is a hydrophyte, or water-plant

Not all hydrophytes, or water-plants, as you may call them, are like these seaweeds. A water-lily is as much a hydrophyte as is a kelp. The water-lily has well-developed food storage areas, as well as tissue designed to carry the food to these areas. The water-lily leaf, the pad, possesses stomata on the upper surface instead of on the under surface, as is commonly the case with land plants. In addition it has developed, through its petiole, extensive air storage and conducting tissue.

Adaptive arrangements related to climatic or atmospheric conditions

We may next note some adaptive arrangements which have a relationship to climatic, or atmospheric, conditions. For example, it is obvious that some arrangements must be made in plants to protect them from the extremes of cold and heat, and particularly from the rigors of the winter months. Perhaps the most obvious method by which a plant succeeds in surviving a severe winter is that of simply storing up underground, when the adverse conditions are not severe, sufficient reserve food so that the parts of the plant above ground may be allowed to die without seriously affecting the vitality of the whole. This is what happens in the bulbs and tubers, which utilize the warm months of the year to store up, by means of their green leaves, enough material to carry them over the winter and start them growing again in the spring. The more the danger of exposure, the deeper will such bulbs and tubers be found to bury themselves. Thus, those which get some protection from masses of fallen leaves under trees will lie immediately under the surface, while those in open meadows, with no such protection, may retire to proportionately greater depths.

Water-plants that escape the cold by sinking deeper into the water

Very interesting it is to note, also, that a comparable proceeding occurs in some of the water-plants, which in lakes and ponds gradually sink deeper and deeper as the cold increases in severity. Thus, the water-soldier, already mentioned, found at the surface during the spring months, takes good care to return to the bottom of the lake before winter begins, and so passes that period at a depth where freezing never occurs. Other plants seek protection by retiring into the mud at the bottom of pools and so on.

How trees and shrubs that remain above ground survive the winter

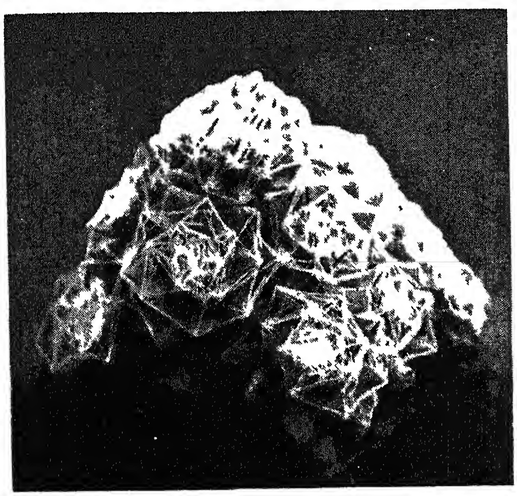
In the case of trees and shrubs that must remain above ground exposed to frost and snow, sufficient food is stored up, as the result of the activity of the green leaves. These delicate structures are then shed in the autumn. The parts of the tree left exposed are not so greatly affected by the cold or other unfavorable conditions prevailing in the winter.

Possibly the great difference between the summer and winter condition of such plants lies in the reduction of surfaces which give off moisture, since under winter conditions in the colder parts of the world it would be impossible for the plants to give off water in winter. This reduced surface is also of advantage in that less opportunity is offered for ice and snow to accumulate in amounts large enough to break the branches of the trees.

Different species of plants exhibit a very remarkable divergence in their capacity to withstand cold. One might think, *a priori,* that a given temperature would

be equally fatal or hostile to all plant protoplasm — in other words, that the same temperature would affect vegetation always in the same way. It is a commonplace of observation, however, that this is by no means the case. Nothing is more familiar than the fact of the difference in the vegetation of different climates. Tropical plants are destroyed even in the moderately severe winters of our own country, while in still colder latitudes the plants which can live outdoors in temperate regions will perish. So that evidently there is some much more profound problem here than is at once apparent. And, as a matter of fact, the problem is one that no botanist can exactly explain.

The other extreme of temperature — namely, great heat — is another case in point in connection with which the plant has certain adaptive structures and arrangements that enable it to cope with the difficulty. The result upon a plant of an exposure to too high a temperature is, curiously enough, very similar to that of exposure to too low a temperature. Here again the problem may be complicated by changes which the excessive heat will produce in the supply of water available from and demanded by the environment. In both cases of excessively high and low temperatures the green parts of the plant may become of a darker color, fade away, and tend to dry up. When this happens from excessive heat, we say that the plant is "burned".



PROTECTIVE CLOTHING OF A PLANT

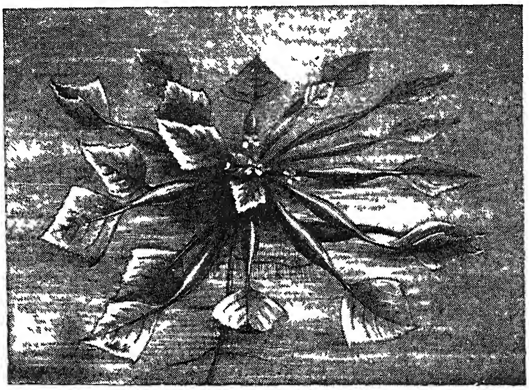
A succulent plant that shades its leaves and protects them from moisture and animal attacks by spider-web-like hairs

Associated with this obvious change is found also an alteration in the cell protoplasm within. It becomes aggregated into little masses in the cells, and separated from the water, which is extracted by the heat. This change depends upon coagulation of albuminous compounds, the destruction of starch granules and the ultimate decomposition of protoplasm. Once more the special constitution of the protoplasm of the plant is that which enables it to select a tropical area in which to flourish. Some of the other points bearing on this matter have already been discussed in connection with leaves.

There are a few cases which, in their efforts to adapt themselves to their special environment, develop actually a sort of floating apparatus. Many of the large algæ of the sea present examples of this. Here we find special modifications of the plant which swell up and act exactly as a float. The cavity of this buoy is perfectly closed, and is quite different from the sort of growth that one finds, for example, in the pitcher-plant, which contains organs for quite another purpose, as we shall see later on. The object of these floats becomes quite apparent when one considers that these plants are more efficient where there is sufficient light to assist in the manufacture of food. The ideal condition does not exist deep down where the plants are attached to the rocks so the buoys serve to keep the plants from settling into the unfavorable deeper water. Many water plants of inland lakes and rivers have air cavities which may function to some extent in bringing portions of the plants to or near the surface. The water-lily is one example of these.

We may just note in passing the modifications found in seaweeds in connection with the process of transpiration. Plants living completely submerged in the water, of course, do not transpire, so we do not find in them either vascular bundles or stomata. No matter how big is the sea-wrack — and some of them are huge — they contain no actual wood. Yet these

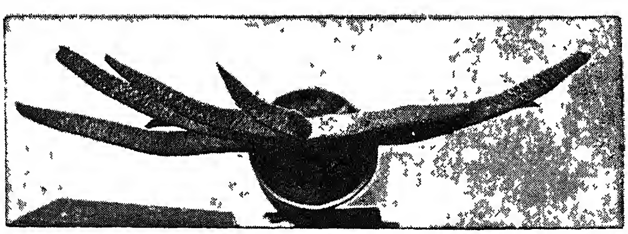
very structures of vascular bundles and stomata and wood are absolutely essential for the life of trees and shrubs. Now, between these two extremes there are endless transitional stages in the degree of moisture of the atmosphere from saturation to almost dryness; and so it becomes necessary for plants to provide some means of promoting transpiration in the one case, and checking it in the other. The former end is obtained by the development on the part of the plant of a large number of cells the surface of which comes in contact with the outer air, these cells being so constructed that they can exhale water. In these cases, too, where it is necessary to facilitate transpiration, there is always a considerable development of green, spongy tissue, which allows the air to penetrate through the leaf. In a word, it is frequently by the increase of leaf surface that transpiration is principally aided. So we may find in some water-plants whose stems and stalks are in the water, and whose leaves float on the surface, that the area of the leaf is a very large one. Indeed, the whole surface of a pond may be covered with floating leaves so arranged that the entire upper surface is exposed to sunlight, while the under surface is colored a violet tint by a pigment, called "anthocyanin", which has the most remarkable property of transforming the rays of light into rays of heat and thereby warming the leaves.


WATER-CHESTNUT, SHOWING FLOATING APPARATUS
This plant was introduced from Eurasia and established in New York and New England

We have referred to the very special conditions of life in the case of water-plants or hydrophytes, and noted some of the special adaptations made by such plants to accommodate themselves to their peculiar environment. For the sake of contrast, we may turn our attention for a moment to those plants which have to sustain life in precisely opposite conditions, plants which are therefore termed xerophytes (Greek, dry + plant).

A xerophyte is a plant which can live even though the water it obtains is of a very small amount. They are drought-loving, or at any rate drought-tolerating, plants. No doubt the first plants in the world were aquatic in their nature and environment, so we must regard the xerophytes as a highly evolved type, exhibiting very special accommodation to circumstances. The conditions under which they live are the most trying conceivable for plants, for they grow in extremely dry soils in regions rainless during long periods.

Among such xerophytic plants we have the yucca, the melon-cactus and other cactus plants, and the date-palm. These last even the parched and arid desert soil of the Sahara cannot quench, though its moisture comes only from springs and climatic conditions are such as to favor the loss of water.


A SUCCULENT PLANT WHICH GROWS ALL ITS LEAVES IN ONE PLACE FOR PROTECTION FROM THE SUN

A true xerophyte, such as a cactus, must transpire slowly, or it would lose what water it gets too soon; and it must have the property of storing up the little water it does obtain. This is the direction in which its special power of adaptation shows itself. The result is seen in the thick, fleshy parts so noticeable in the cacti, the aloes, the stone-crops and similar plants, structures in

which the moisture is carefully stored up for the use of the plant. It is found, too, that the outer skin, or epidermis, of these plants has become extremely thick, and has the power of reviving itself in a wonderful manner, even though it has become dried up. It is not, however, in the leaves only that drought-loving plants exhibit specialization. In some of them the roots are also adapted for water-storage. More often, perhaps, the stems are peculiarly formed, being of immense thickness in proportion to their length when compared with ordinary land plants. These stems contain a large quantity of water. In fact, the plant may be practically nothing but stem, as a cactus is. This obviously reduces the transpiration surface to a minimum.

Even where a xerophyte has well-developed leaves we find they are so arranged as to be exposed to the heat and light as little as possible. The most extreme examples have no leaves at all, but the whole stem is green in its outer part, and does the work usually allotted to the leaf. This is seen in the cactus. The leaves are, in fact, transformed into formidable spines. The formation of all the organic compounds for the plant has therefore to be carried out by the green stem.

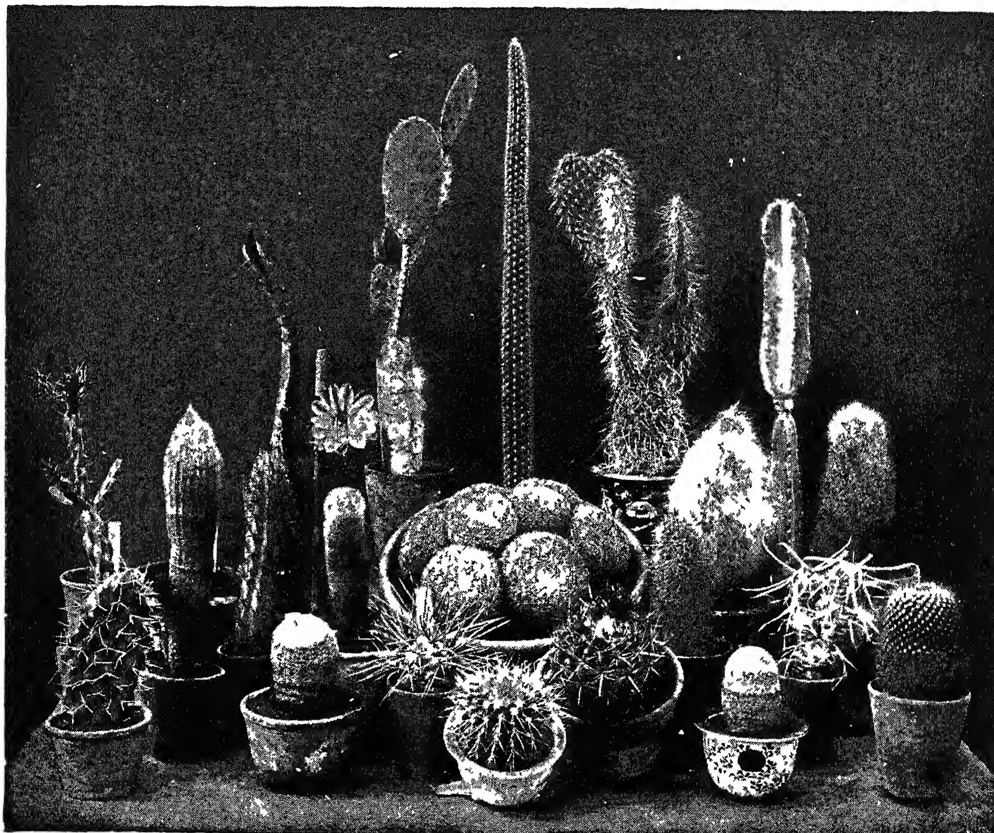
The cactus deserves rather special notice in connection with the study of adaptive arrangements, because it contradicts our usual notions of what the parts of a plant should be like. We generally think of any large plant as having a somewhat brownish stem, carrying a certain number of green leaves. Here we find exactly the reverse. The stem is green, carries no leaves that look like leaves, but instead has a number of brownish or gray spines upon it. The function of the modified leaf, or spine as it now is, is to protect the green stem from injury, this stem being the producer of the organic material we expect to find made by the leaf. Many of these protective spines grow to great length, and are so strong as to make extremely formidable weapons of defense against animals that would otherwise feed upon the green stems as the only green food-stuff in the district.

THE DATE-PALM THAT EVEN THE ARID DESERT SOIL CANNOT QUENCH

The spines are of very variable shapes and character, and it occasionally happens that the same species of cactus carries

upon it spines of different kinds and size. They present a curious and striking appearance, and this possibly has led to the cactus being a favorite plant for cultivation in gardens. If these spines be carefully examined it will be found that the most formidable of them are arranged in such a way as best to protect that portion of the green stem which is the most active or, in other words, the greenest.

A careful study of the illustration in this chapter of the group of cacti plants will give an excellent impression of the variation in form which they exhibit. Some are almost like balls, others elongated, thick or fleshy masses; while in others the stem is broken up into separate parts or branches resembling thick-leaved plants. The leaf-like discs of the prickly pear are specially noticeable.



A GROUP OF CACTUS PLANTS THAT ARE SPECIALLY ADAPTED TO HOT AND DRY COUNTRIES

The necessity for such extraordinary protection will be realized if we remember the conditions of the environment of the plant. Everything else upon the arid plain has been scorched to a dull brown. The cactus alone remains green, an inviting spectacle for hungry animals. Little wonder is it that nature has been hard pushed to devise some means to preserve it from extinction under such circumstances, and so we find the formidable spines, associated with the green, apparently leafless stem.

In the preceding paragraphs we have selected a number of widely differing conditions in the presence of any one of which plant life must make some special effort in order to live. We have, however, merely touched the fringe of a very large subject — namely, that of the study of how plants adapt themselves to external relations. What has been said, however, may perhaps serve as an introduction to the general idea of adaptation, one of the most interesting provisions of nature.

ANIMAL FRIENDS AND FOES

An Imminent Danger from the Upsetting by Man of the Natural Balance of Wild Life

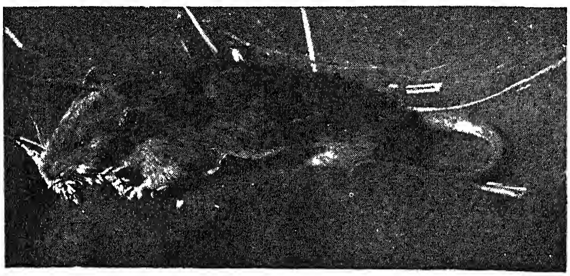
ENORMOUS LOSS FROM PROLIFIC PESTS

SOME day, when man's relations with the animal world are intelligently controlled and directed, we may have a law, insisting that, if a natural safeguard against the over-multiplication of injurious forms of animal life be removed, another as effective shall be provided. The destruction of nature's police will be recognized as an offense as serious as arson — or killing game in the closed season! We fine or imprison the vandal who takes rabbit, pheasant or partridge out of season but the man who cries out against such vandalism is at liberty to slay weasel and skunk, owl and hawk — anything that might conceivably snatch a nestling from the birds he preserves for the mere joy of shooting. The death of every one of the carnivorous animals and birds mentioned represents, in its effects, a serious loss to the country. The death of each means immunity from capture for so many rats, mice and voles.

Of these, the house rats and mice alone cost the United States over $200,000,000 a year. Field-mice, or voles, constitute recurrent plagues, and in the past have brought great losses to agriculturists in Utah, Nevada, California and other parts of the United States as well as in Scotland, England and other parts of the Old World. In Europe water-voles, or water-rats, ruin whole plantations of trees near their haunts, and sometimes work swift destruction on a whole country-side by tunneling through the banks of canals, rivers and dykes. The bank-voles rob trees of their bark, and ruin timber growths by climbing the trunk to a height of ten or more feet, and, by eating the lateral and terminal buds, produce dwarfed and distorted stems Mice pillage harvest field, granary and stack, besides consuming and spoiling huge quantities of food and goods in dwellings and other buildings. It is a law of nature that the number of individuals of a species shall remain, through a course of years, practically stationary. We have seen, in previous chapters, notably in that dealing with the bulk of the rodents, by what ruthless processes the mean is preserved. But if man in his selfish folly removes the checks which nature furnishes, then the balance must of necessity be upset. And, such checks having been removed, the balance of nature *is* disturbed; the earth is plagued today with that remnant of the rodents for which consideration is reserved to the present chapter.

Carnivorous birds and animals alone cannot keep down this plague, but their slaughter deprives us of our most potent natural aid. These furred and feathered police are mainly nocturnal, and so are the animals upon which they prey. The average man does not see a rat a year, yet they are, with the mice and voles, the most numerous animals in the land, and unparalleled as workers of mischief. We have no means of estimating the number of rodents killed by a weasel, but we do know that, for every one it kills for food, it slays a dozen more to gratify that strange instinct for slaughter which makes it so redoubtable an ally against vermin. The owl's good work may be estimated from superficial evidence: traces of hundreds of rats and mice mark the site of its nest.

Now, every couple of rats that these birds or animals destroy might, if left to multiply become the ancestors, in the course of twelve months, of eight hundred other rats. They can breed in every month of the year. and do produce from six to seven litters, ranging from six to nineteen, with an average of ten or eleven. One female, kept under observation, produced seven litters in as many months. The young, though not attaining full development until eighteen months old, begin to breed before the end of the fourth month. And they live and multiply at the cost of human health and property. Mice and voles, too, are appallingly prolific, and would command general attention as a menace to agricultural and commercial prosperity were not their case rendered relatively less serious by comparison with that against the rat. As weeds and insect pests spread across a continent, so do rats, but at an infinitely quicker pace. And the damage they could do is almost beyond comprehension. Their operations recently led to the undermining of some masonry and the bursting of three reservoirs in Connecticut. Their ravages at Turin necessitated the employment of tin cases for correspondence at the post-office. Their gnawing at insulated electric wires is one of the all too frequent causes of short circuiting resulting in disastrous fires which have been traced back directly to these pests. Children, even grown people, are often attacked and bitten. They travel, too, by rail and steamer, and incalculable damage to foodstuffs and other goods is annually wrought by rats at the New York docks in spite of precautionary measures.


THE DOMINANT BROWN RAT

Turning to the hygienic aspect of the subject, modern bacteriological research has shown that the rat is a veritable nursery of all the noxious disease germs which endanger the health of man. Rooting into all manner of festering garbage, the rat absorbs and becomes the host of the most virulent forms of microbic growth. Not only plague, but, in Germany, trichinosis, is directly propagated by the rat; and it is more than suspected that swine fever, rinderpest and certain other forms of disease are spread abroad by the rat, if not actually originating in his body.

Cultures of the germs taken from the moist nose of a recently killed rat have revealed the presence of almost every known disease germ — even the microbe which has been proved to be the cause of tetanus (lockjaw). The spread of influenza among horses is now traced to the agency of rats. By getting into the bins and nosing among the grain, they leave the germs behind for the subsequent introduction into the body of the horse.


THE BLACK RAT, NOW ALMOST EXTINCT HERE

When, some years ago, a mysterious sickness broke out in England, it was not until the seventh fatality that suspicion of its nature was aroused. Then, bacterial cultures having been made from the blood of one of the victims, the plague bacillus was detected. Pneumonic plague, the most alarming form of the malady, had returned to England after centuries of absence and was raging within an hour's railway ride of London. Although it luckily attacked fewer than a score of people, of whom only ten died, yet the disease was found to be widespread among rats, rabbits, hares and other animals throughout a considerable area.

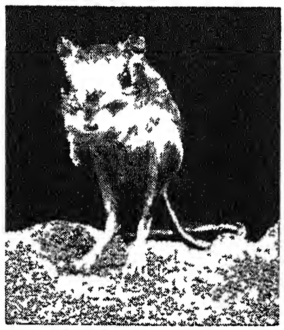
It was remembered, too late to save life, that a number of dead rats had been seen in the neighborhood, and that many of them had been handled. The origin of the plague among human beings then became clear. Of a large number of rats examined, 5 per cent were found to be plague-infected. During the outbreak of plague in Sydney the percentage of rats similarly affected was never higher than 37 per cent; while of the thousands of these animals caught and examined in Bombay, when the plague there was at its height, the average was rarely higher than 6 per cent

Plague, originating in Hongkong in 1894, had reached Bombay two years later, and up to the end of 1910 had carried off at least seven million British subjects, a million having died in the Punjab alone in the course of seven years. It had reached Japan and Russia, and in 1907 and 1908 broke out in San Francisco, where 77 deaths occurred before it was checked. Nearly a half a million rats were trapped during the crusade against them and probably as many more were poisoned. Then came the terrible outbreak in Manchuria. In the latter case the marmot was blamed, but there was no doubt as to the rat being the origin elsewhere. Japan carried out a rat campaign, and in Tokyo four and a half millions of the rodents were destroyed in three years. The Japanese soldiers fighting during the winter against Russia were provided with fine warm protectors for nose and ears; and these protectors proved to be made of the skins of the rats for which the Japanese government had been paying about a fortieth of a cent each! But, in spite of this great slaughter, it was estimated that the rat population of Tokyo was greater than ever! The survivors, having the normal food supply for division among lesser numbers, bred with greater freedom than ever. Both Japan and India abandoned the attempt to exterminate the rat as hopeless Yet so long as there are a few rats in the world, there is always the likelihood of an outbreak of plague.

THE FISH-RATS OF AUSTRALIA

The infected rat is bitten by a flea, which acts as host for the plague bacillus. That flea infects whatever living victim it may bite. From one rat and its fleas, many rats may become infected, and among the many one rat will pass on its parasite to a human being The rat-flea caused an outbreak of bubonic plague in Glasgow a few years ago, where in the course of a single year 120 rats were found to be infected with *bacillus pestis* as was the case in San Francisco. But in England the plague was pneumonic instead of bubonic. In the latter form the ailment manifests itself as a fatal disease of certain glands; in pneumonic plague it is the lungs which are attacked. The English is really the worse form, for the breath of a patient may cause death to every person near; the bubonic form is not infectious; in each case it must be preceded by the bite of an infected rat-flea.

The voice of science has gone forth against the rat. "If we are to stamp out plague we must first stamp out the rat." Both the black rat and the brown rat are equally susceptible to the disease. It was the black rat which, arriving in Great Britain in the early Middle Ages, brought the plague with it. The black rat has never been exterminated, although it exists in the United States in infinitely smaller numbers than its brown-gray cousin, the more powerful and savage beast that has driven it away by direct attack and by process of starving out.


THE KANGAROO RAT

Poorer countries such as Denmark and Portugal have conducted national crusades against these loathsome vermin; Hamburg has been driven to provide what is called a 'rat-killer battleship" for the protection of her port against plague-infected rats carried by ships from other harbors. Concerted action will have to be taken in the United States.

The twelve most important measures needed for repressing rats and mice, as recommended by the United States Department of Agriculture, are the following:

1. The requirement that all new buildings erected shall be made rat-proof under competent inspection.


THE GAMBIAN POUCHED RAT

2. That all existing rat-proof buildings shall be closed against rats and mice by having all openings accessible to those animals, from foundation to roof, closed or screened by door, window, grating or meshed-wire netting.

3. That all buildings not of rat-proof construction shall be made so by remodeling, by the use of materials that cannot be pierced by rats, or by elevation.

4. The protection of our native hawks, owls and smaller predatory mammals — the natural enemies of rats.

5. Greater cleanliness about markets, grocery stores, warehouses, courts, alleys, stables, and vacant lots in cities and villages, and like care on farms and suburban premises. This includes the storage of all waste and garbage in tightly covered vessels and the prompt collection and disposal of it each day.

6. Care in the construction of drains and sewers, so as not to provide entrance and retreats for rats. Old brick sewers in cities should be replaced by concrete or tile.

7. The early threshing and marketing of grains on farms, so that stacks and mows shall not furnish harborage and food for rats.

8. Removal of outlying straw stacks and piles of trash or lumber that harbor rats in fields and vacant lots.

9. The keeping of provisions, seed grain and foodstuffs in rat-proof containers.

10. Keeping efficient rat dogs, especially on farms and in city warehouses.

11. The systematic destruction of rats, whenever and wherever possible, by trapping, poisoning and organized hunts.

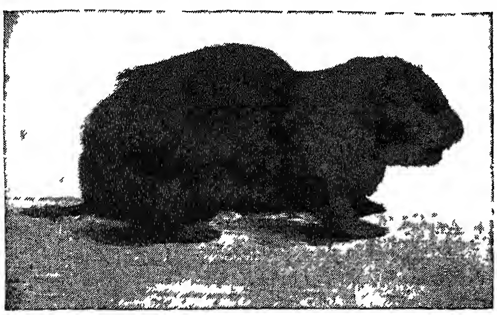
12. The organization of clubs and other societies for systematic warfare on rats.

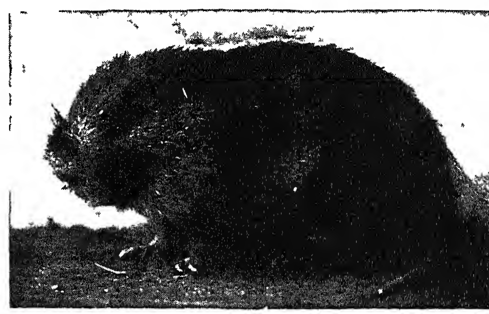
Perhaps the most satisfactory poison is barium carbonate, which can be spread upon various baits such as fish, cheese, bread and butter, or anything that the rats have been eating, or mixed into a stiff dough of oatmeal or cornmeal. Greater success is obtained by using several different baits.

It is indeed imperative that not a bird or animal which can help to keep the rat in check should be killed. Owls should be rigorously protected by law, and even weasels be vouchsafed at least a closed season.

While one of these rapacious little animals may occasionally take a rabbit, pheasant or a partridge, and even break and enter the domestic poultry run, what is the cash value of such prey? What, on the other hand, is the cash value of the crops which by killing rats, it saves to the farmer? Above all, what is the cash value to the nation of the human lives safeguarded from plague by these enemies of the rat which slay vast numbers of death-disseminating vermin?

There is one rodent that indirectly contributes to the food harvests of the world. Manitoba grows the finest grain, but has no earthworms to fertilize its soil. From Manitoba, and indeed throughout all that part of North America lying to the south of the Saskatchewan and west of the Mississippi, pocket-gophers are the great soil-makers. The deep, rich layer of soil from which the golden grain springs is the creation of these little rodents, who have mixed up the deep deposit of decayed vegetation with the underlying loam. By their burrowing and tunneling they have unconsciously prepared for man some of the finest, most fertile soil in the world. But the rest of their order levy heavy toll for this one benefit, so much so, indeed, that it has now proven necessary to wage a war of wholesale destruction and in many places they have been successfully exterminated by means of poisoned baits.


THE HAIRY BAMBOO-RAT


THE CANE-RAT

The rats and mice are an extraordinarily numerous family. Excluding the dormouse and dormouse-like forms, and the jumping mice, which are relegated to two different families, there are between thirty and forty genera of these animals. These, however, include rodents not popularly regarded as allied to rats and mice — such as the hamsters and lemmings and gerbils. The classification of this family must constitute a perplexing problem to the newcomer into the realm of natural history; for while the dormice are referred to one family, and the jumping mice to a second, which includes the true jerboas, the harvest mice are relegated to the genus comprising the true rats and mice, which is the thirty-first genus of the mouse tribe, while the tree-mice and the climbing mice, though included in the same family group with the latter, are far removed from genus thirty-one.

There are three known genera of dormice — the common, the squirrel-tailed and the garden. The first, well known throughout Europe, is arboreal and squirrel-like in habits. The second is widely distributed in other parts of Europe, though absent from Scandinavia and Great Britain. The true dormouse has a more limited European range, but is found in Siberia, and has an ally in the brightly colored little Persian species known as the painted dormouse. The garden dormouse, which swarms in southern Europe, where it does great damage to fruit, is interesting as one of the few animals known to be immune to snake-bite. Not only is this mouse immune, but its blood, after an infusion of snake venom, immunizes other animals submitted to inoculation. Closely allied to the dormice are the spiny mice of India and China, strange little animals haunting large trees or excavating small hollows. They have developed a defensive armor very similar to that of the "fretful" porcupine, and are a sort of stickle-back among rodents.

The jumping mice, with their elongated hind legs, curiously resemble the jerboa, but they exceed even that animal in activity. A jumping mouse possesses, says an observer, a momentary agility second to no other rodent, and a muscular strength of enormous power for so small a creature. Its leaps measure eight to ten feet in length, though they rapidly diminish to half the former distance. It can elude the weasel and the snake, and by a swift manœuver escape the attention of hawk or owl. Unlike most mice, the jumping mouse spends the winter in a state of hibernation in a warm nest underground.

Australia possesses two native rodents, of which one is a genus of water-rat. As it is essentially an aquatic animal, it has so far not proved obnoxious. The gerbils follow almost immediately in the classification, but are far different in appearance, though in the same family. They are restricted to the Old World. Jerboa-like, they jump twelve to fifteen feet at a bound, and are exceedingly difficult to catch. They are a pest to cultivated crops wherever found in the vicinity of human dwellings. While the Old World possesses white-tailed rats, which the New World lacks, America has white-footed mice, unknown elsewhere. They are essentially woodland mice, but they frequently get into dwellings, where they are often caught in mouse traps. They make engaging pets and are easily distinguished from the house mice by their snowy-white feet and underparts, their large eyes and ears and their rich fawn color. While ordinarily terrestrial, living about stumps and fallen logs, they do not hesitate to climb trees and often make their homes in old birds' nests by putting on a roof and cutting an entrance through the bottom or one side.

As the otter and other carnivora have taken to life in or about the water, so have certain rats other than the so-called "true" water-rats. Conspicuous among these are the specialized fish-rats of South America, which make their homes in the mountain streams of Peru and Ecuador, where small fish constitute their diet. One species has already lost its external ear, while these conches are gradually disappearing from the ears of *Anotomys leander*, a species found in the highest streams of Ecuador — another example of evolution before our eyes

THE FIELD-VOLE OF EUROPE

THE WATER-VOLE, OR WATER-RAT, OF EUROPE

A further adaptation to circumstances, as we must deem it, is found in the habits of the Florida wood-rat, the young of which cling, opossum-like, to the back and sides of the doe as the latter runs about in search of food. A rat we ought to know more about is the crested rat of Abyssinia, Somaliland and eastern Africa. This strange creature has a crest of hairs, some of them as much as $3\frac{1}{2}$ inches in length, which can be erected at will. In the hind foot the small front toe is opposable to the others, and serves as a thumb.

The short-tailed field mice, of which there are about fifty species found in the United States, are among the most destructive pests of farming and fruit-growing districts. It has been estimated that the annual loss to crops, nurseries and

orchards amounts to over $3,000,000 every year, while during times of the so-called "plagues", the loss is much heavier. The most familiar members of this group of mice are the common field mouse, the pine mouse and the European water-rat. They are short, chunky mice with tiny eyes and small ears almost concealed by their thick fur. They run on the ground, or burrow into banks, often riddling whole fields with their burrows, cutting off the grains close to the ground, ruining alfalfa, and girdling trees often of considerable size. They are especially numerous about marshes and wet meadows or wherever grass is left uncut, where their spherical nests are built beneath the matted vegetation. They are nearly as prolific as house rats, and where their natural enemies are few, soon overrun the whole countryside.

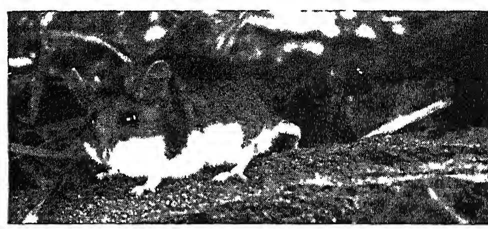
The largest of the North American rats and the most valuable is the muskrat, a water-loving animal whose fur has gained rapidly in popularity. It was mentioned among the home builders of Chapter 14 because of the large dome-shaped houses which it builds in marshes. It is found, however, wherever there is permanent water throughout North America east of the Rockies, and, with the skunk, provides the chief income of the trapper.

There are several other mice and rats and rat-like animals — bandicoot rats of southern Asia, bush-rats of India and Africa,


THE COMMON HOUSE MOUSE


THE COMMON MEADOW MOUSE


Photo by A A Allen
THE COMMON JUMPING MOUSE


THE WHITE-FOOTED OR DEER MOUSE

giant rats of the Philippines — one, the whip-tailed, having a body-length of 18 inches and a tail 15 inches in length, and a second giant rat of the same latitude renowned as a tree-climber. Then we have the mole-rats, the bamboo-rats, sand-rats — almost hairless, these latter — the kangaroo rats, so-called, not from any relation to the marsupials, but from the shape and proportions of the hind legs and their kangaroo-like progression. Another of the rat-like group, the octodont tribe, is said to contain twenty-seven genera, distributed over Africa, the West Indies and South and Central America. Among them we have the curious African gundis and cane-rats, the Chilian and Peruvian degu, and the South American tucuto, an animal which, like the mole and one or two other animals, is slowly sacrificing sight to touch.

All these animals are, without qualification, enemies to man in so far as they destroy his food, his flowers, his potential timber. Many of them are difficult of access. Given sufficient food, they multiply with extraordinary rapidity. And it is a simple fact that at present man depends rather upon their natural enemies than upon his own efforts, not, indeed, for their extermination, for that is not an immediate possibility even were it desirable, but for maintaining some sort of check upon their increase.

Although it may occasionally help itself to poultry, the mungoose is decidedly an

ally of man, in that it wages war upon his enemies. It is a member of a diversified assemblage of animals, which, including the true civets or civet-cats, the genets, ichneumons (or mungooses), foussa linsang, palm civets, etc., is grouped as the civet tribe External outline suggests kinship with the weasels; but whereas the latter are from the same stock as the bears and raccoons, the civets are linked, through the foussa, with the cat tribe. The foussa is peculiar to Madagascar, and, being a strictly nocturnal, unamiable creature, has not been as closely studied as it ought to be There is some reason to believe that the foussa is the descendant of small, cat-like animals whose fossil remains are found in

A FAT DORMOUSE

Oligocene Tertiary deposits in France — an interesting theory, in view of the fact that the existing lemurs of Madagascar are thought possibly to be descended from extinct French lemurs.

The civets are nearly all exclusively carnivorous, untiring hunters, and, as to most species, expert tree-climbers, thanks to their retractile or semi-retractile claws. They are all nocturnal, hunting for food when the "small game" on which they prey are also abroad. But, as all the world knows, the civet has an economic value in respect of the peculiar scented secretion which collects in the perineal glands of the animal. This secretion, which enters the scent pouches in the form of a thick fluid, hardens upon reaching the air, and retains a penetrating odor which makes it highly esteemed in the East as a perfume. Formerly the secretion was held to possess valuable medicinal properties, as, indeed, most of the unlikely animal products were. In order that the civet perfume may be obtained, the animal is kept in captivity, and, at the right time, placed in a long, narrow cage which prevents it from turning to use teeth or claws. The substance is then painlessly extracted, by means of a bone instrument, from the pouch in which it is contained. The perfume is obtained from the African civet, the Indian civet (of Bengal, China and the Malayan region), from another species of distribution practically similar to that of the last named, and from the rasse, the smallest member of the group, which is found in India, Ceylon, Java, China and elsewhere in Oriental lands.

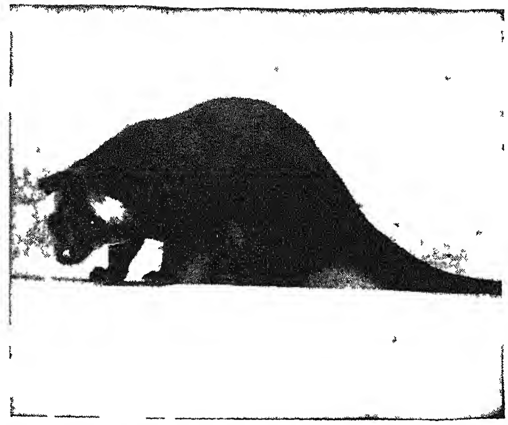
The gentle genet used in southern Europe as a houseguard against mice

The genets, which lack the scent-secreting glands of the true civets, are confined to Africa and parts of Europe and southwestern Asia. Although very little different in temperament from the rest of their family, genets are easily tamed where man has taken the trouble to try the experiment. They are commonly kept in southern Europe as houseguards against rats and mice. Passing the linsangs, active, carnivorous little animals which eke out their diet with insect additions, we reach the palm-civets, of which there are several species, tree-haunting animals which derive their name from their habit of drinking the palm-juice which has been collected by natives in vessels hung upon the trunks of palm-trees.

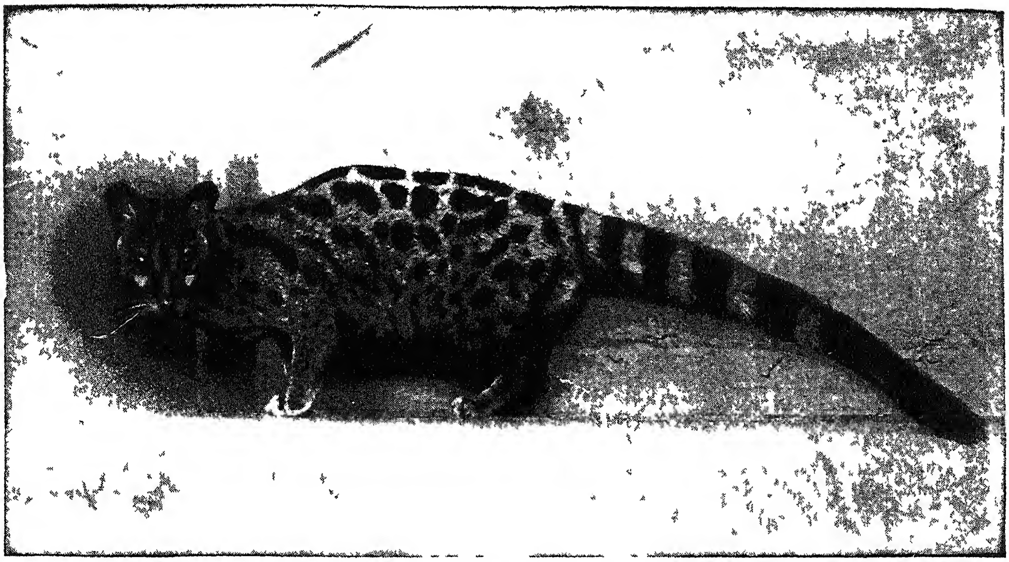
A near relative is the binturong, in the young of which the tail is completely prehensile, and even in the heavier adult never quite loses its gripping power. The range of the binturong is purely Oriental. The civet family has a semi-aquatic representative in the water-civet which, quite as much at home in river and stream as the otter, is yet a first-rate tree-climber and hunter upon land.

TYPICAL MEMBERS OF THE CIVET TRIBE

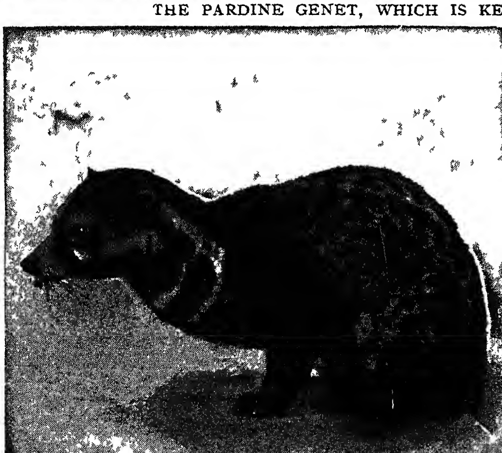
THE BANDED MUNGOOSE, OR CUSIMANSE



THE WHITE-WHISKERED PALM CIVET



THE PARDINE GENET, WHICH IS KEPT AS A PET IN SOUTHERN EUROPE



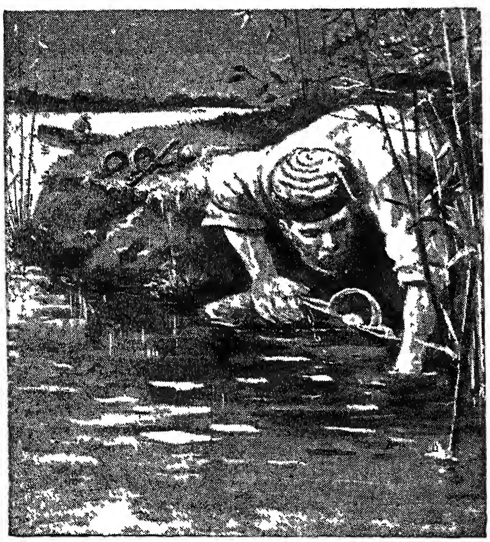
THE SUMATRAN CIVET

THE MEERKAT, OR SURICATE

The photographs on this and preceding pages are by Lewis Medland, W P Dando, C Grant Lane, T A Metcalfe, A.A Allen, and others.

The mungoose, a fine and fierce hunter, and also an affectionate pet

The mungooses share with the genets the distinction of sole representation of the civet-like group in Europe. The European type (genus *Herpestes*) is also spread over Africa, India and the Malayan countries. In this genus are included all the true mungooses, some dozen or more species. The remainder are grouped in nine distinct genera, exclusive of the meerkats. Of this number, Madagascar claims four genera, and one, the *Eupleres goudoti*, appears from its teeth to be dependent solely upon an insectivorous diet. It is



SETTING SPRING TRAPS FOR THE MUSKRAT

with the common mungoose, however, that we are more concerned. It is a fierce little creature when its liberty is suddenly threatened, but few animals are more easily tamed, and few show greater affection and gentleness toward human beings. The mungoose is not only the great enemy of snakes, it is incomparably the finest hunter of rats and mice, insects, and the noisome lizards which infest Oriental dwellings. A mungoose will rid ship or house of rats and other vermin, but it will poach poultry if permitted to do so, just as a well-fed cat may occasionally do. The Egyptian mungoose is an enthusiastic devourer of crocodile eggs, and just as assiduous a hunter of snakes and other undesirable forms of life. There can be no doubt that the mungoose is one of the most potent animal allies that man has in the East against the loathsome rat, to say nothing of its service against snakes. It was long a debated point as to whether the marvelous activity of the little carnivore protected it from the deadly poison fangs of the snake, but experiment has shown that the mungoose is practically immune to serpent venom.

The drawback of giving any predatory animal free breeding room

Of course, it is not suggested that mungooses live simply to oblige us by killing our enemies; mungooses, excellent as allies, themselves become a pest by overmultiplication, as an experiment in Jamaica proved. When rats overran the island and threatened the entire ruin of the sugar-planting industry of the region, mungooses were introduced as a last hope. They exterminated the rats, but, their own food supply running low with the shortage of rats, they played havoc with other forms of life, both animal and bird, and the outcome was a succession of insect pests as destructive as the rats. Then the mungooses had in turn to be removed.

Jamaica's experiment was an object-lesson. Rats, permitted to multiply without check, brought the island to the verge of ruin; and the remedy, artificially applied, eventually proved as costly as the ill. Upon a wider and therefore less obvious scale a similar thing is in progress throughout Great Britain. Almost all of the free natural enemies of rats and mice have been obliterated and they are paying a yearly toll of about $75,000,000 and an occasional human life to the rodents. In spite of this lesson, the people of the United States have little more care for the services of the friendly hawks and owls and never for a moment consider the necessity for preserving foxes and coyotes. skunks and weasels. Rodents are already costing us over $200,000,000 a year. Think what it will be when their natural enemies are as scarce here as they are at present in the British Isles.

Science and Progress (1815-95) III

by JUSTUS SCHIFFERES

LIGHT AND OTHER ELECTROMAGNETIC WAVES

ONE of the chief aims of scientific theories is to show the kinship of things and events in nature — to point out that apparently unrelated phenomena are intimately connected. Isaac Newton achieved this result when he showed that the fall of an apple on earth and the course of a planet through the heavens are both governed by the same laws of universal gravitation. A group of brilliant scientists of the nineteenth century — Faraday, Maxwell and Hertz, among others — made the same sort of unifying generalization. For they demonstrated the intimate connection between light, electricity and magnetism; showed the existence of radio waves; and discovered that light, heat and radio waves are all electromagnetic radiations. We of the twentieth century enjoy the fruits of this momentous discovery in the form of radio, television, radar and scores of other useful devices.

Before the electromagnetic theory of light and similar radiations could be worked out, it was necessary to have a clearer idea of the nature and properties of light. As we saw in a previous chapter (pages 1123-24) two theories concerning the nature of light had been put forward. The emission, or corpuscular, theory of light, advanced by the great Sir Isaac Newton, was that light consisted of tiny particles (called corpuscles) thrown out by the source of the light. The contrary theory, held by the Dutch scientist Christian Huygens, was that light traveled from point to point as a wave moving through an invisible medium called ether. About the only thing that the partisans of Newton and Huygens agreed on was that light had a finite, not an infinite, velocity: that is, that it took time for it to travel from one place to another. Because of the reverence accorded to Newton's authority, the corpuscular theory of light was accepted by most scientists throughout the eighteenth century.

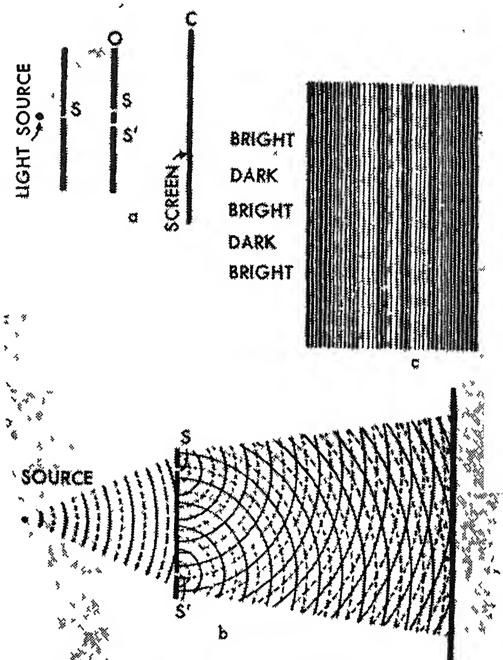
In the early part of the nineteenth century, the wave theory of light was newly and strongly championed by the Englishman Young and the Frenchman Fresnel. Thomas Young (1773–1829) was a man of many unusual talents. Trained as a physician but freed from the drudgery of practice by a large inheritance from an uncle, he worked on a great variety of scientific projects. He was the first to describe and measure astigmatism (a defect of the lens of the eye causing indistinct vision). He was the first, too, to explain color sensation as due to the presence in the retina of three kinds of nerve fibers, corresponding to red, green and violet light respectively. He was also interested in navigation, serving as superintendent of the NAUTICAL ALMANAC and secretary of the Board of Longitude. He helped to decipher Egyptian hieroglyphics. A professor at the Royal Institution of London, he delivered lectures that gave new meaning to the concept of energy and to the idea of capillarity (the flow and rise of liquids through tiny tubes, such as the smallest blood vessels). Young's scientific reputation rests chiefly, perhaps, on the phenomenon called interference and his demonstration of the wave theory of light.

"The proposition which I mean to insist on at present," wrote Young in 1803, "is simply this: that fringes of colors are

produced by the interference of two portions of light." He showed that this was so by means of an ingenious, but very simple, experiment. He made two pinholes close together in a piece of cardboard. A beam of sunlight was directed through the pinholes onto another piece of cardboard serving as a screen. When the two beams overlapped on this screen, their light was divided into plainly visible dark stripes and light bands. Young had observed similar effects in the case of waves of water and pulses of sound, which are also waves. "It has been shown," he said, "that two equal series of waves, proceeding from centers near each other, may be seen to destroy each other's effects at certain points and redouble them at other points." Young concluded, therefore, that the light was traveling through the pinholes in the form of waves. The light bands in the experiment represented the points at which the waves of light from each pinhole were reinforcing each other; the dark stripes represented the points at which the waves were canceling each other.

Young called the waves "undulations"; he maintained that light of any color consists of "undulations of given breadth." He calculated the breadth — or the wave length, as we would say today — of these undulations and found them to be exceedingly small quantities. "The undulations constituting the extreme red light," he wrote, "must be, in air, about 1/36,000 of an inch and those of the extreme violet about 1/60,000."

The interference experiments of Young aroused the enthusiasm of the French physicist Augustin-Jean Fresnel (1788–1827), who referred admiringly to "the beautiful results that Dr. Thomas Young has already obtained with the rare wisdom that characterizes him." Fresnel's education had been slowed down by the disease — tuberculosis — that eventually caused his death; but he had won praise for his mathematical ability at the Polytechnic School and he had graduated from an engineering school. He set to work to make an abstract study of light waves, often in collaboration with Arago.



From Bowen C Dees, *Fundamentals of Physics*, 1945; The New Home Library, Doubleday and Co, Inc

Thomas Young. Above is a diagram of his famous interference experiment (described on this page), by which he sought to show that light consists of waves.

Fresnel made many experiments on the polarization of light. Light is polarized by passing it through a special kind of glass or crystal so that its waves — "undulations" or vibrations — move only in one direction instead of helter-skelter. From his experiments on the polarization of light, Fresnel came to a very important conclu-

sion: namely, that the vibrations in a ray of light are transverse — that is, that they are at right angles to the direction in which the light travels. In other words, when light is traveling forward — say, from a distant star to your eye — its vibrations are moving continuously up and down, and *not* forward and backward. Fresnel assumed that light consists of "vibrations in the ether similar to sound waves" He went on to observe: "In nature vibrations are never isolated. They always repeat themselves a great many times, as in the swing of a pendulum or the vibrations of a tuning fork."

From the viewpoint of the beholder, light is the interpretation that the brain makes of certain types and lengths of waves which fall upon the retina of the eye. When you are struck in the eye, you "see stars" — that is, the blow is interpreted in the brain as flashes of light. If you put a hot cloth upon the eye, other nerve pathways will carry impulses of other types of waves, which your brain will interpret as heat. As we shall see, there are various other kinds of invisible waves that the human mind, with the aid of scientific theory and instruments, is now able to apprehend. Thus, radio waves are not directly audible or visible to the human sense organs. Their effects, however, transmitted through the proper instruments, can be *seen* and *heard* in a television set.

Both Young and Fresnel took for granted the concept of the ether, first advanced by Huygens in the seventeenth century. The ether theory is based on the assumption that if light consists of waves it must pass through some medium or other, just as sound waves are carried in and by the surrounding air. Consider what happens when waves of sound move through the billions upon billions of particles that make up the air. A disturbance — the ringing of a bell, a revolver shot, the meowing of a cat — causes the particles of air nearest the disturbance (call them A particles) to bump into their neighbors, which we shall call B particles. The A particles bounce back, the B particles bump into the adjacent C particles and so on. The series of collisions brings about variations in the pressure of the air; the variations are transmitted through the air at the rate of roughly a mile in five seconds and ultimately reach the eardrum of the listener. The air, then — that is, the billions of particles that make up the air — acts as a medium for the transmission of sound. Suppose you set an alarm clock going in a bell jar that is being evacuated by means of a vacuum pump. When practically all the air has been pumped out (a perfect vacuum is not possible), you will no longer hear the alarm bell. (Air is not the only medium through which sound waves can be transmitted; they also make their way through liquids, such as water, and solids, such as steel.)

Why the concept of ether was introduced

Air is obviously not the medium through which light waves move, for they can easily pass through the best vacuum that can be produced on earth. That is why Huygens felt called on to invent his "luminiferous [light-carrying] ether" as the medium for the transmission of waves of light. The ether, according to Huygens' theory, consists of immeasurably tiny particles, perfectly hard and elastic; he held that they bounce back and forth and transmit the motions of light without themselves being visibly moved. Not only Young and Fresnel but later researchers like Maxwell and Hertz unquestioningly accepted the existence of the ether. Yet, as we shall see, the concept was eliminated, to all intents and purposes, before the end of the nineteenth century. The ether was, after all, only a scaffold on which to build theories about the phenomena of light.

Following the researches of Young and Fresnel, two French physicists, Armand-Hippolyte-Louis Fizeau (1819–96) and Jean-Bernard-Léon Foucault (1819–68) devised different methods for determining more accurately the velocity of light. Galileo had tried to measure the speed of light with a series of lanterns blinking from various hilltops, but he had not succeeded. Olaus Roemer had suc-

JEAN FOUCAULT

ceeded in obtaining an approximate figure by studying a series of eclipses of one of the satellites of Jupiter (see page 1126). Fizeau and Foucault obtained a more accurate value than Roemer.

Fizeau measured the velocity of light by passing a beam of light through the gaps in a rapidly rotating toothed wheel, which looked and turned something like a buzz saw. The light passed through the gap between the teeth to a distant mirror and was reflected back by the mirror to the wheel; it was viewed through a telescope set up at a carefully measured distance away. When the wheel was run at a given speed, the tooth that bounded a given gap on one side would move over to cover the gap just as the reflected light would reach the wheel; the light would be blocked off and the observer would not be able to see it through the telescope. If the wheel were made to turn at twice its former speed, the following gap would occupy the place of the first gap, and the observer would see the light. Since all the factors involved were known, including the speed at which the wheel turned, the velocity of light could be calculated accordingly.

Foucault's measurements were made with a rapidly rotating mirror. He directed a beam of light upon this mirror, and the light was reflected to another mirror which had been set up a measured distance away from the first. The second mirror then reflected the light back to the first one. Since the rotating mirror had turned through a definite angle in the meantime, the velocity of light could be computed by measuring this angle. According to the calculations of Fizeau and Foucault the figure in question was about 300,000 kilometers (186,300 miles) per second. The latest figure is 186,280 miles per second.

It is not surprising that Foucault should have used rotating mirrors for his experiments, for he did much research on the phenomenon of rotation. As a result of these studies, he invented the gyroscope — the spinning top that maintains its equilibrium — and he devised the famous pendulum experiment that demonstrates the rotation of the earth on its own axis (see page 257).

In the 1840's Michael Faraday, one of the great pioneers of electrical research, made an important contribution to the theory of light. On the basis of an experiment involving the plane polarization of light and a magnetic field (see page 1930), he suggested that light waves might be transverse vibrations traveling along the lines of electric and magnetic force. Faraday was no mathematician; he had no other guide than his marvelous intuition in advancing this amazingly modern concept. An English physicist with excellent training in mathematics — James Clerk Maxwell (1831–79) — soon sought to back up Faraday's conclusions by means of a rigorous mathematical analysis.

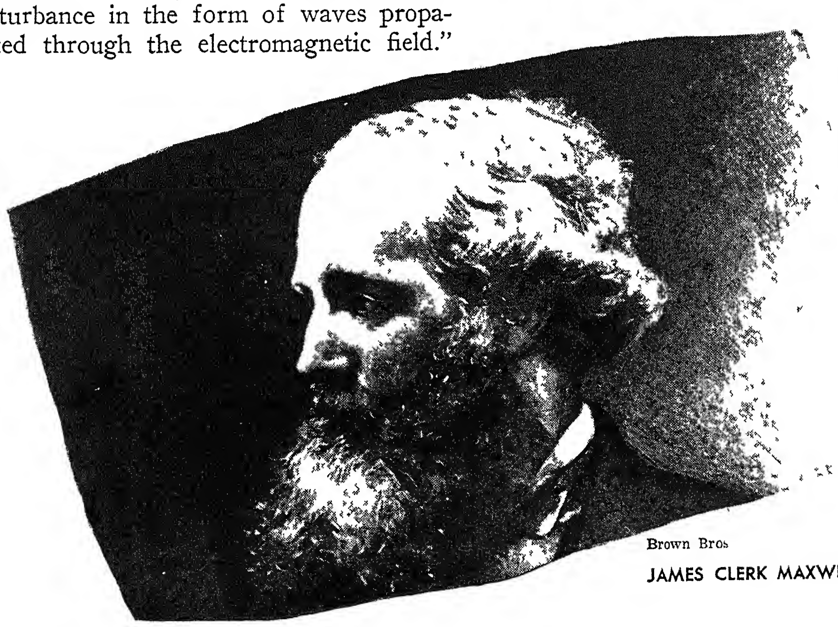
Born and educated in Edinburgh, Scotland, Maxwell was successively professor of physics at Marischal College, Aberdeen, professor of physics and astronomy at King's College, London, and, from 1871, professor of experimental physics at Cambridge, where he supervised the building of the famous Cavendish laboratory. His scientific genius was apparent early. At fifteen he wrote a paper on a mechanical method for tracing Cartesian ovals. (A Cartesian oval is a particular kind of curve described in analytic geometry.) At eighteen he made notable con-

tributions to the study of the equilibrium of elastic solids. He wrote a prize essay on the stability of Saturn's rings; he was one of the outstanding authorities of his day in electricity, optics and thermodynamics (the flow of heat).

Maxwell sought to find out what conclusions could be drawn from Faraday's suggestion that light might be an electromagnetic phenomenon. The preliminary results of Maxwell's researches appeared in a paper, The Dynamical Theory of the Electromagnetic Field (1865). His fully developed ideas on electromagnetism were presented eight years later in his TREATISE ON ELECTRICITY AND MAGNETISM, one of the classics of scientific literature. Maxwell held that the phenomena associated with magnetism and electricity are due to stress and motion taking place in a material medium — the ether. This medium was capable of displacement "similar to that [slight, elastic yielding of parts] which takes place in structures and machines owing to the want of perfect rigidity in the connections." These continuous displacements, Maxwell thought, resulted in the propagation of electricity and magnetism in space. He concluded that "light itself (including radiant heat and other radiations, if any) is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field." All these radiations, he held, move through space at identical speeds.

Thus far Faraday's intuition and Maxwell's mathematical analysis had produced only a theory, which had not been put to the test of experiment. It remained to be proved that electromagnetic radiations other than visible light and radiant heat really existed and could be detected. A young German professor, Heinrich Rudolph Hertz (1857–94), finally succeeded in demonstrating the existence of such radiations. Born in Hamburg, Hertz studied engineering and physics at Munich and Berlin. For several years he served as assistant to the distinguished physicist and physiologist Hermann von Helmholtz; he was then appointed instructor at the University of Kiel. Later he became professor of physics in the technical high school at Karlsruhe, where he carried out the researches that made him famous. In 1889 he was named professor at the University of Bonn; five years later he died at the early age of thirty-six. Hertz was a brilliant and high-minded researcher, following the best traditions of the German universities, which were then in their heyday.

Here are some of the questions that Hertz was trying to answer — questions that had been raised by Maxwell's theory.



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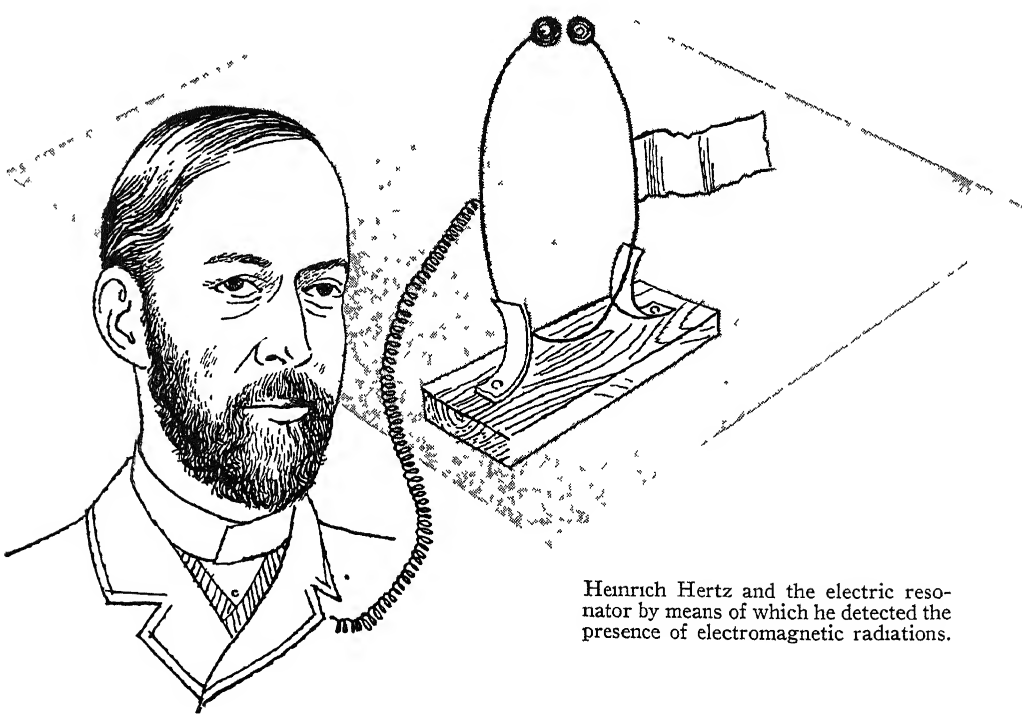
JAMES CLERK MAXWELL

Do electricity and magnetic forces require time for their propagation? When we rapidly electrify and discharge a body, do the resulting "electromagnetic disturbances" spread out in waves through space? Since these waves travel with the speed of light (that is, more than 186,000 miles per second) can we devise an apparatus that will detect them?

To answer these questions, Hertz had to have an apparatus that could produce appropriate "electromagnetic disturbances." He found that such a device was readily available; it was the electric oscillator. In the oscillator, the coiled wire winding of an electromagnet was connected with an electric battery and circuit-closing switch or key. This wire winding, called the primary winding, had only a small number of turns. Additional wire was wound with many turns on top of the primary winding; these added turns of wire were known as the secondary winding. The electric "pressure" produced in the primary winding was greatly increased in strength in the secondary winding. The terminal wires of the latter were connected to two metal balls, so mounted that a minute gap separated them. Sparks appeared across this gap when the key in the primary circuit was closed.

A spark is a clearly visible electromagnetic disturbance. It is not a continuous process. Like the much slower vibration of a violin string, the spark is made up of a number of intermittent changes in the direction of the force that is involved — electrical force, in the case of the oscillator The changes in direction, or periods or frequencies are called oscillations; they may range as high as 300,000,000 a second Obviously we cannot make out the individual oscillations, but we can see their aggregate result in the form of sparks.

The stream of sparks passing across a spark gap in an electric oscillator provided Hertz with a suitable source of electromagnetic radiations. His next problem was to devise an apparatus that would reveal the presence of these radiations, thus indicating clearly that they had been traveling, at the speed of light, through space.



Heinrich Hertz and the electric resonator by means of which he detected the presence of electromagnetic radiations.

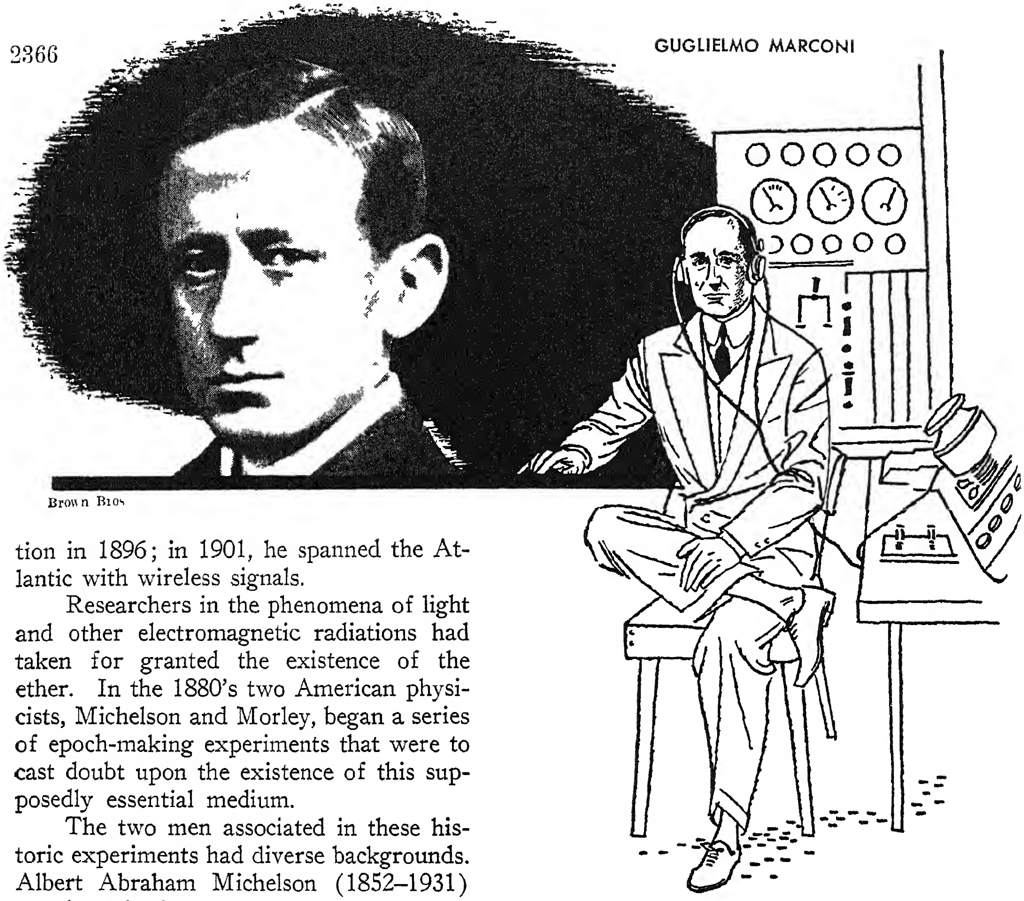
The detecting device that Hertz contrived turned out to be amazingly simple; it consisted merely of a hoop of copper wire with a break in it. When the oscillator began to produce sparks and the hoop was held at the right distance from it, sparks could be seen to jump across the break — the spark gap — in the hoop. "The method had to be found by experience," wrote Hertz, "for no amount of thought would have enabled me to predict that it would work satisfactorily. The sparks are microscopically short, scarcely a hundredth of a millimeter long; they only last about a millionth of a second. It almost seems absurd and impossible that they should be visible; but in a perfectly dark room they are visible to an eye which has been well rested in the dark. Upon this thin thread hung the success of our undertaking."

Hertz had discovered the secret of the electromagnetic radiations that were at first called hertzian waves in his honor and that are now known as radio waves. At this point in the investigation it was particularly important for Hertz to show that these newly discovered radiations were really waves. He carried his copper hoop — which he called an electric resonator — all around the darkened room of his laboratory. In certain places, it produced sparks; in others, none. The "spark areas" and the "dead-spot areas" followed each other in ordered succession, suggesting the alternate "union and extinction of colors" in Young's famous experiment, described above. Here apparently was proof that the hertzian waves were waves indeed, since they showed the effects of interference, as in the case of light waves. To bolster up this thesis Hertz tried a good many other experiments. He found that radio waves acted in much the same way as waves of light and radiant heat. They could be reflected, refracted and polarized.

In the years to come, the theory that light and heat and radio waves are all electromagnetic radiations gradually won general acceptance. We realize now that there are other kinds of electromagnetic radiations. The sum total of these radiations forms what is called a complete electromagnetic spectrum. Arranged in the order of increasing wave lengths, the radiations in this spectrum include gamma rays, X rays, ultraviolet rays, visible light (from violet to red), infrared (heat) rays and radio waves. They all have the velocity of light — 186,280 miles per second; they differ only in wave length and, accordingly, in frequency.

The discovery of hertzian, or radio, waves represented a magnificent scientific triumph; but for a time these waves had no practical application. The first demonstration that they could be used to convey signals through space was made by the Italian inventor Guglielmo Marconi (1874–1937). Born at Bologna, Italy, of an Irish mother and an Italian father, young Marconi became interested in hertzian waves while he was still in his teens, and he soon became convinced that they could be put to practical use. He set up a successful "wireless telegraph" in his father's garden near Bologna. On opposite sides of the garden he erected poles from which were suspended plates of tin, serving as aerials. One plate was for the receiving set, the other for the sending set. By happy accident he had grounded both sets.

The sending set still utilized the induction coil and spark gap that had served Hertz. But a new feature had been added to the receiving set. This was a device called a coherer — a glass tube filled with iron filings, which "cohered," or stuck together, under the influence of hertzian waves. This instrument was the discovery of the French physicist Edouard Branly; it had been used in Russia by A. S. Popov to detect electromagnetic waves propagated by lightning discharges. Marconi improved the coherer by attaching an automatic tapping device, which "decohered" the circuit. A telegraph recorder was placed in the circuit to take down the dots and dashes carried via the radio waves. The system worked; the taller the aerial poles, the better it worked. Marconi had shown that through the medium of radio waves messages could be sent through "empty space." He took out British patents on his inven-



GUGLIELMO MARCONI

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tion in 1896; in 1901, he spanned the Atlantic with wireless signals.

Researchers in the phenomena of light and other electromagnetic radiations had taken for granted the existence of the ether. In the 1880's two American physicists, Michelson and Morley, began a series of epoch-making experiments that were to cast doubt upon the existence of this supposedly essential medium.

The two men associated in these historic experiments had diverse backgrounds. Albert Abraham Michelson (1852–1931) was born in Germany and was brought to the United States at the age of two. He was graduated from the United States Naval Academy at Annapolis in 1873 and thereafter taught physics and chemistry at that institution. Later he became professor of physics at the Case School of Applied Science in Cleveland and at the University of Chicago. He received the Nobel Prize in physics in 1907 for his numerous experiments involving the measurement of light. His experimental associate, Edward Williams Morley (1838–1923), was a native of Newark, New Jersey, and a graduate of Williams College. From 1869 he was professor of chemistry at Western Reserve University in Cleveland.

These two scientists proposed to find out if ether really exists and if it fills all space, even that which is inside of solid bodies. They reasoned this way: If ether fills all space and if the earth, in its journey through space, is rushing around the sun at the rate of 66,000 miles an hour, the ether should be at rest while the earth moves through it. Since, from the point of view of earth-bound creatures, the earth is standing still, the ether would appear to us on earth to be moving; it would be drifting through the laboratory "like the wind through a grove of trees."

How could this relative motion be detected? Delicate measurements of the speed of light — presumably passing through the ether as its medium — should tell the story. If the ether exists, light should travel faster when it moves with the ether than when it moves against it. To measure the supposedly different velocities of light, Michelson and Morley set up apparatus consisting mostly of mirrors and micrometers. The apparatus was mounted on a massive stone floating in mercury to permit turning in a full circle and to overcome any experimental errors

that might be introduced by the vibration of the delicately adjusted apparatus. With this equipment Michelson and Morley measured the speed of light when it was traveling parallel to the line of the earth's motion and when it was at right angles to this line.

But measure as they might — day or night, autumn, winter, spring or summer — the light appeared to travel just as rapidly with the "ether stream" as against it. Gravely the two experimenters concluded that "if there be any relative motion between the earth and the luminiferous ether, it must be quite small."

Their findings proved exceedingly troubling to physicists. It left them with new and troublesome problems to solve; it left the concept of ether dangling, and so it remains to the present day. Most scientists today consider the concept outworn and useless. They still hold that light and X rays and radio waves are electromagnetic radiations in space; but they maintain that new conceptions of space have made a luminiferous medium unnecessary.

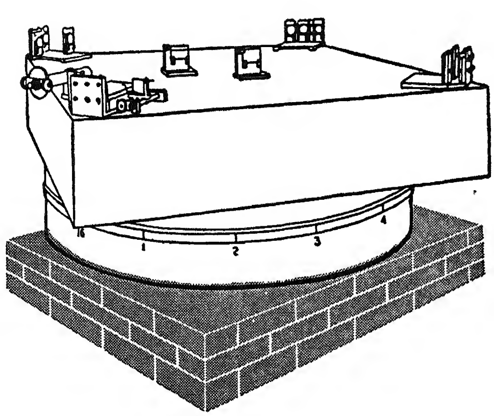
THE CONSERVATION OF ENERGY

Energy is the capacity for performing work — that is, for exerting a force through a certain distance. When you lift a stone, you are at one and the same time exercising your muscles, using force, doing work and releasing energy. We are apt to think of energy in terms of muscular activity. But the machines that science and technology have created to do the work of the world have in general substituted other forms of energy for human and animal exertion. Civilized man, translating scientific discoveries into practical inventions, has learned how to transform one type of energy into another type with remarkable effects.

Thus, for example, chemical energy, released when coal is fired under a boiler, can be transformed into mechanical energy when the steam from the boiler moves the pistons of an engine. Mechanical energy represented by the moving pistons can be transformed into electrical energy, as when a steam engine turns a dynamo. Electrical energy, in turn, can be changed into heat energy when electricity is used to run an electric stove; and so on over and over again. Energy cycles like this are everywhere in evidence. In tracing these cycles, it is customary to distinguish between potential energy, or stored-up energy, capable of doing work, and kinetic energy, or energy that is actually used in doing work

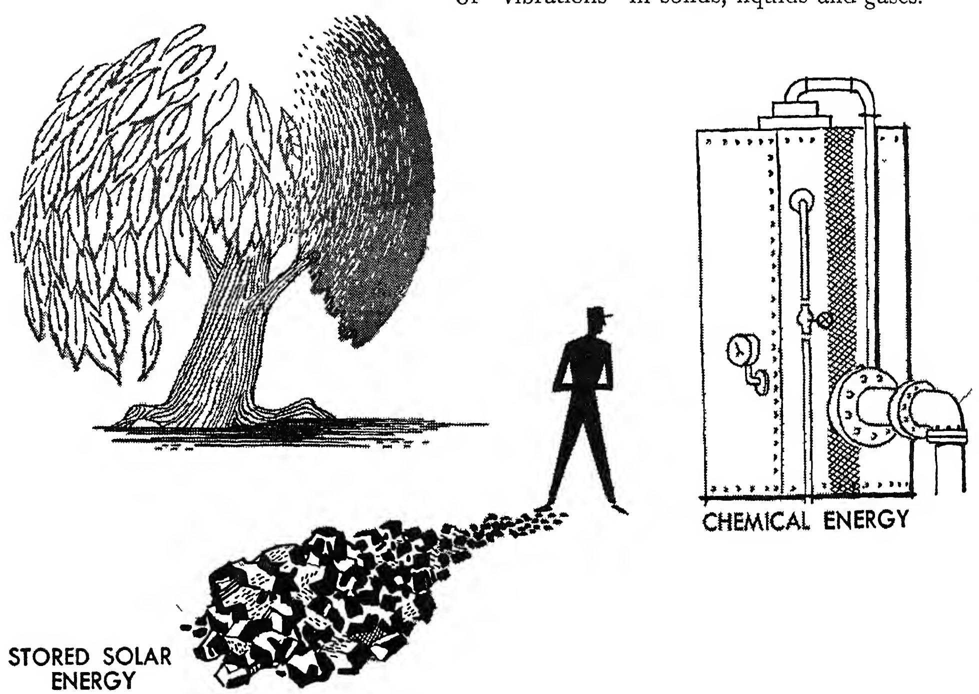
The law or principle of the conservation of energy was one of the great contributions of the nineteenth century to the development of science; it is associated with the names of Joule, Von Helmholtz and other physicists. The chemists of the eighteenth century, notably Lavoisier, had previously established the doctrine of the conservation of matter; namely, that matter cannot be destroyed. Joule and the others, as we shall see, asserted and demonstrated in effect that energy could not be annihilated — only transformed.

In the nineteenth century a rigid distinction was made between matter and energy. But the scientists of the twentieth century have devastatingly demonstrated that matter can be transformed into energy. This is, of course, the story of atomic energy and the atom bomb, which



From W. F. Magie, *A Source Book in Physics*, McGraw Hill, 1935

Drawing of the Michelson-Morley apparatus, described on the preceding page.



will be told in later chapters. The sun, from which all the sources of energy and power on earth eventually derive, probably gets a large share of its radiant energy by transforming matter into energy and vice versa (see pages 1443-45).

The theory of the conservation of energy arose out of the study of heat. In their analysis of the effects of heat, the chemists of the late eighteenth century had gotten rid of the false theory of phlogiston (see page 1120), but they had substituted an equally erroneous idea in its place. They still looked upon heat, or "caloric," as they called it, as a form of matter — a peculiar kind of "imponderable fluid." They thought that the heat produced by friction was something squeezed out of the materials that were rubbed together. This theory persisted until well into the nineteenth century.

Yet long before the theory of caloric had been demolished, it had been under vigorous attack. As early as 1738 the Swiss physicist Daniel Bernoulli had suggested that temperature, which measures the intensity of heat, was really a measure of "vibrations" in solids, liquids and gases. In other words, he thought of heat itself as essentially consisting, not of matter, but of vibrations — that is, he considered it to be a form of motion. A half century later, the American-born scientist Benjamin Thompson (1753–1814), who later became a count (Count Rumford) of the Holy Roman Empire, further developed this idea.

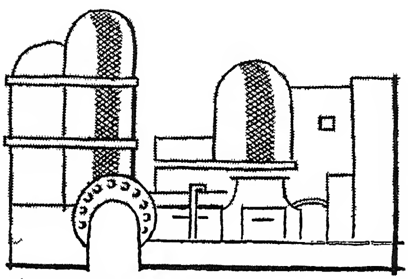
Thompson, or Rumford, as he is generally referred to, had espoused the royal cause in the American Revolution. He left his native land, bound for England, in 1776, and he spent the rest of his adventurous life in Europe. Though a British citizen, he obtained leave from the British

Government to enter the service of the Elector of Bavaria; he remained in Munich for twelve years in the Elector's service as Minister of War, Minister of Police and Grand Chamberlain. He can be considered as one of the first "social scientists," because of his efforts to help the Elector ease the desperate economic plight of his subjects. Rumford tackled the problem by seeking to improve housing conditions and to provide economical means of preparing and keeping food. Accordingly, he found out how to eliminate smoky chimneys, and he introduced central heating, based on convection currents of water. He also invented the steam table, the casserole, the chafing dish and the coffee percolator. (Incidentally, he extolled the virtues of coffee!)

Rumford did more, perhaps, than any other man to demonstrate that heat is a form of motion and not a form of matter. In the year 1798 he performed the critical experiments that led him to adopt this conclusion. He has left us a graphic account of these experiments.

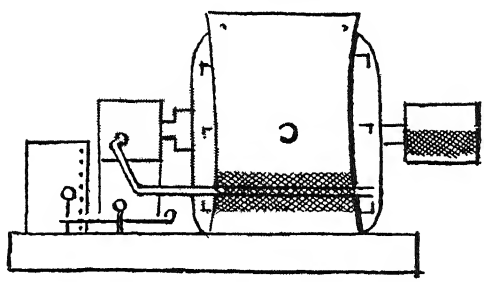
"Being engaged lately," he tells us, "in supervising the boring of a cannon in the workshop of the military arsenal at Munich, I was struck with the very considerable degree of heat which a brass gun acquires in a short time in being bored; and with the still more intense heat (much greater than that of boiling water, as I found by experiment) of the metallic chips separated from it by the borer."

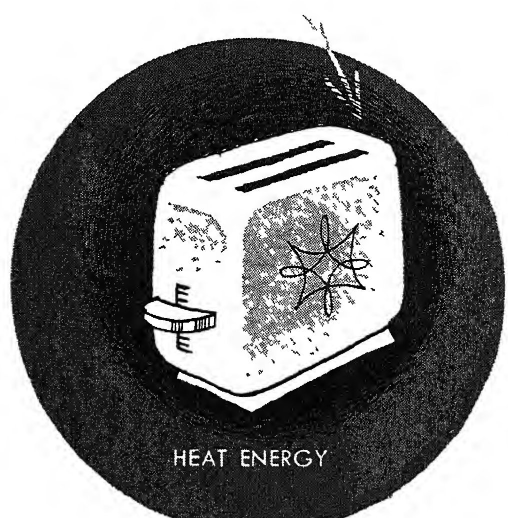
In one of his experiments Rumford utilized the heat generated by a steel cannon-borer to raise the temperature of 2¼ gallons of cold water, which had been placed in an insulated and watertight box in contact with the cannon barrel In the space of two and a half hours, the water in the insulated box actually boiled.



MECHANICAL ENERGY

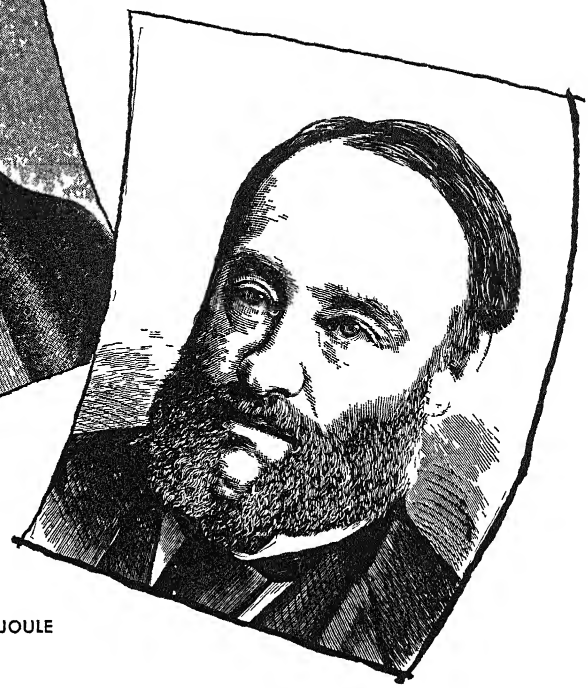
ELECTRICAL ENERGY





Transformations of energy. The stored solar energy in coal is transformed into chemical energy when it is fired under a boiler. Chemical energy is changed into mechanical energy when steam from the boiler moves the blades of a turbine. Mechanical energy is transformed into electrical energy in the dynamo. Finally electrical energy is changed into heat energy whenever toast is prepared in the electric toaster.

COUNT RUMFORD



Both pictures Culver Service

JAMES P JOULE

"It would be difficult," he wrote, "to describe the surprise and astonishment expressed in the countenance of the bystanders on seeing so large a quantity of water heated and actually made to boil without any fire . . . The source of heat generated by friction in these experiments appeared evidently to be inexhaustible It is hardly necessary to add that anything which any insulated body or system of bodies can continue to furnish without limitations cannot possibly be a material substance (like caloric); and it appears to me difficult, if not quite impossible, to form any distinct idea of anything capable of being excited and communicated, in the manner that heat was excited and communicated in these experiments, except it be *motion* "

A simple experiment by the eminent English scientist Sir Humphry Davy backed Rumford's findings. Davy placed two pieces of ice in a vacuum in surroundings with a temperature below zero. Then he rubbed the two pieces of ice together. The resulting friction produced heat in spite of the subzero surroundings, and the ice melted

When energy is transformed, therefore, or converted into another form, heat is the usual product. Heat itself is a form of energy since it consists of molecules in motion. (See page 166) When a cannon is bored, say, by a workman, the muscular energy of the workman is transformed into heat energy. Does this heat energy disappear once it has produced its effects? A resounding "No" was the answer of the eminent brewer-scientist James Prescott Joule (1818–89). A bearded and God-fearing Victorian gentleman, he had inherited a brewery in Manchester, England, his birthplace, from his father; but he showed far greater interest in pure physical research than he did in the art of brewing.

In a lecture delivered to a church

meeting in 1847, Joule set forth his doctrine that energy, which he called living force (*vis viva*), is not destroyed as it is dissipated. "When I employ the term 'living force,'" he said, "you will understand the force of bodies in motion. . . . You will at once perceive that the living force of which we have been speaking is one of the most important qualities with which matter can be endowed and, as such, it would be absurd to suppose that it can be destroyed. . . . You will therefore be surprised to hear that until very recently the universal opinion has been that living force could be absolutely and irrevocably destroyed at any one's option. Thus, when a weight falls to the ground, it has been generally supposed that its living force is absolutely annihilated and that the labor which may have been expanded in raising it to the elevation from which it fell has been entirely thrown away and wasted. . . . It is manifestly absurd to suppose that the powers with which God has endowed matter can be destroyed any more than they can be created by man's agency.

"Experiment has shown that wherever living force is apparently destroyed or absorbed, heat is produced. . . . By fifteen or twenty smart and quick strokes of a hammer on the end of an iron rod of about a quarter of an inch in diameter placed upon an anvil, an expert blacksmith will render that end of the iron visibly hot. Here heat is produced by the absorption of the living force of the descending hammer in the soft iron.

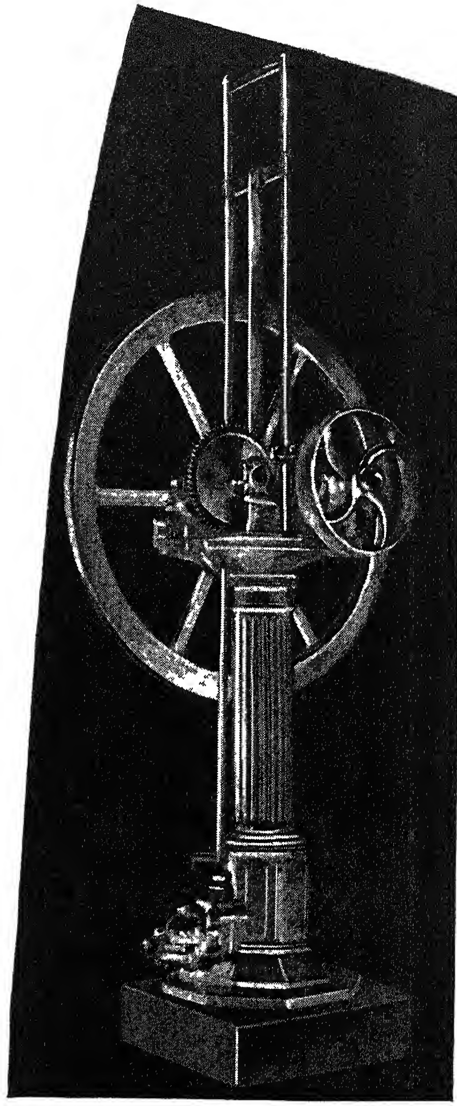
"In these conversions nothing is ever lost. The same quantity of heat will always be converted into the same quantity of living force. Thus the attraction of 817 pounds [778 pounds is the corrected figure] through the space of one foot . . . is equivalent to the quantity of heat which can increase the temperature of one pound of water by one degree Fahrenheit. . . . Behold, then, the wonderful arrangements of creation."

To arrive at the numerical figure for the mechanical equivalent of heat Joule devised a number of ingenious experiments. He often set up his experimental devices in a cool brewery cellar where there would be no sudden change in temperature A typical apparatus was a series of paddle wheels, turned by falling weights in cans holding water, oil or mercury. The paddle wheels were made to turn by known

HERMANN VON HELMHOLTZ

weights falling through measured distances. Joule carefully measured the resulting increase in the temperature of the liquid, and this permitted him to calculate the mechanical equivalent of heat. Joule also calculated the heat equivalents of electrical energy (see page 1932).

A cantankerous German physician Julius Robert von Mayer (1814–78) disputed the priority of Joule's concept of the conservation of energy. He does indeed seem to have given the first explicit statement *in print* of this concept. Mayer, born in Heilbronn, son of a druggist, went to sea as a ship's surgeon. Not having much to do on shipboard, he amused himself with mathematical fancies and thus hit on the idea of the equivalence of work and heat. He was again practicing medicine on dry land when he published in the year 1842, in a magazine devoted to chemistry and pharmacy, his statement of the conservation of energy and the mechanical equivalent of heat. Mayer's conclusions were not based on careful experimentation, as in the case of Joule, but on mathematical analysis.

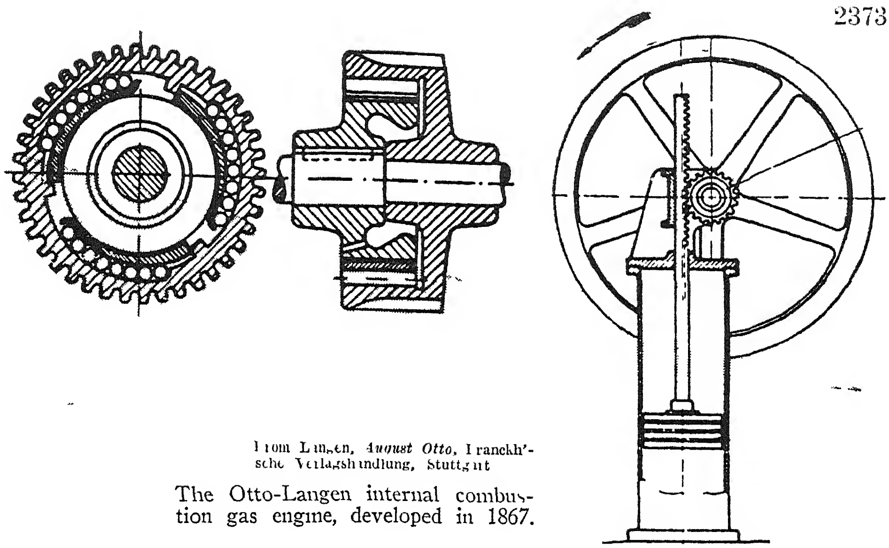


A mathematical analysis of the conservation of energy

"Forces are causes," he wrote, "and they are related to each other by the simple principle: cause equals effect (C = E). . . . In a chain of causes and effects, as plainly appears from the equation, a term or part of a term can never become equal to nothing. The first property of all causes may be called their indestructibility. . . . We must also regard the magnitudes [bigness or smallness] under which one and the same object makes its appearance. The capacity for assuming various forms is the second essential property of all causes . . . hence a force once in existence cannot be annihilated; it can only change its form.

"Unless we recognize a cause-and-effect relationship between heat and motion," he wrote, "it is just as hard to explain the production of heat as it is to account for the disappearance of motion. . . . As I have found, water undergoes a rise in temperature when violently shaken. Whence comes this quantity of heat?" His answer is: "The heat must naturally be equivalent to the motion. . . . A locomotive engine with its train may be compared to a distilling apparatus; the heat applied under the boiler passes off as motion, and this is deposited again as heat at the axles of the wheels."

The phrase "conservation of energy" (*Erhaltung der Kraft,* in German) was coined and made popular by Hermann von Helmholtz (1821–94). On July 23, 1847, Von Helmholtz, then a twenty-six-year-old German army surgeon, read his paper On the Conservation of Energy at a meeting of the Physical Society of Berlin. He



From Langen, *August Otto*, Franckh'sche Verlagshandlung, Stuttgart

The Otto-Langen internal combustion gas engine, developed in 1867.

set forth the startling doctrine that the law of the conservation of energy was applicable everywhere — in living things as well as in inanimate objects. He considered it as a universal law of nature and a new guiding principle in the study of natural sciences. This was a daring generalization in Von Helmholtz' day; it has become an accepted working tenet of scientific belief.

Von Helmholtz' paper created a sensation and assured the author's reputation. He quickly rose to an eminent position in the German university system. He taught physiology, anatomy and physics; he held chairs at different times in the foremost universities of Germany — Koenigsberg, Bonn, Heidelberg, Berlin — and he became the director of the Physico-Technical Institution at Charlottenburg. He was in his day a champion of academic freedom, a doctrine not yet universally established.

He distinguished himself in many different fields. In 1851 he invented the ophthalmoscope, a mirrored instrument with which it is possible to examine the interior of the eye. "Von Helmholtz has opened a new world to us!" exclaimed a grateful colleague. Among the other problems he worked on were the measurement of the rate of transmission of nerve impulses, the mechanisms of sight and color vision and the mechanism of hearing — which led him into the fields of tone qualities, aesthetics and the theory of music. He is commonly regarded as one of the founders of experimental psychology.

With Joule, Mayer and Von Helmholtz the doctrine of the conservation of energy was firmly established. Many important questions about energy in the form of heat remained unanswered For example, if heat is a form of motion, what is actually moving? Again, if all energy is conserved, what happens to the energy that *appears* to be lost? Out of questions like these grew the science of thermodynamics, or the study of the flow of heat. This science is associated with the names of Nicolas-Léonard-Sadi Carnot, Josiah Willard Gibbs, Baron Kelvin, Rudolf Julius Emanuel Clausius, James Clerk Maxwell and Ludwig Boltzmann.

The rise of the kinetic theory of gases

As to the question "What moves to create heat?" the nineteenth-century scientists came to the still tenable conclusion that it was the molecules of which all tangible substances are composed. (Today we look even deeper and assume motions within the molecules) That molecular motions create heat can be verified by everyday experience. When you use a simple hand pump with a piston to inflate a bicycle tire, you can feel the cylinder of the pump grow hot under your hand. This heat is produced mainly because the compression

of the air in the metal cylinder has increased the number of fast-moving air molecules beating against its inner walls. This is a simple demonstration of the kinetic theory of gases, which nineteenth-century physicists like Joule and Maxwell expanded out of the ideas about molecules in gases previously developed by chemists like Avogadro.

Another problem that profoundly interested the physicists of the nineteenth century was the dissipation of energy. Though energy does not disappear, there is abundant evidence that a certain amount of it is dissipated, or wasted. When you row a boat, for example, most of the muscular energy you exert is used to move the boat through the water. But some of this energy serves only to heat your body. The added body heat — "useless" heat — does not help you propel the boat; it passes off into the air around you.

Carnot's studies in the dissipation of energy

A young captain of engineers in the French Army, Nicolas-Léonard-Sadi Carnot (1796–1832) was one of the first to call attention to the dissipation of energy. In a paper The Motive Power of Heat, published in 1824, he pointed out that some heat must always be dissipated and lost and that no man could ever construct a steam engine — or any other kind of engine — that would be 100 per cent efficient. He pointed out, too, that "the production of the motive power in a steam engine . . . is due to . . . the *transfer of heat from a hotter to a colder body.*"

Carnot's work was carefully re-examined by Sir William Thomson (Baron Kelvin), the man who had made the Atlantic cable work, and by the German physicist Rudolf Julius Emanuel Clausius (1822–88). From this study they eventually drew the following conclusion: "Heat cannot of itself, without the performance of work by some external agency, pass from a colder to a warmer body." This is called the second law of thermodynamics; the first law is the principle of the conservation of energy. We can say, roughly, that the tendency of heat is to spread itself out like water, until it finds a level — state of equilibrium — where all things are of the same temperature.

Lord Kelvin and many other nineteenth-century scientists, riveting their attention on the "waste" and dissipation of useful energy, arrived at the gloomy philosophical speculation that the total energy in the universe would eventually be so evenly spread out that the flow of heat from the sun to the earth would cease. These men saw the universe itself as constantly running down in its energy supply, like a clock spring that could never be rewound. But they were quite wrong! Solar energy, at least, we are quite certain today, constantly restores itself by processes of atomic fission and atomic fusion. (See the article on atomic energy in Volume 4.)

There was a practical, as well as a philosophical, side to the study of thermodynamics in the nineteenth century. It resulted in the development of better steam engines, both stationary and locomotive. A typical advance in design was the compound (triple expansion) steam engine constructed by McNaughton in 1845. Inventors also sought to develop an internal-combustion engine that would do away with the need for steam. (Steam engines are external-combustion engines.) One of the first to succeed was Nikolaus August Otto (1832–91), a German technician and mechanic, who, working with Eugen Langen, invented an internal-combustion engine in 1867. About a decade later, in 1876, he developed a four-cycle engine whose fuel was gasoline exploded by an electrical spark. Another German mechanical engineer, Rudolf Diesel (1858–1913), patented the first diesel engine in 1892. The most efficient type of heat engine, the diesel uses crude oil for fuel and requires no spark for ignition.

The rapid, economical and convenient transportation available in the twentieth century is one of the products of nineteenth-century research in the conservation of energy and the flow of heat.

SCIENCE THROUGH THE AGES is continued on page 2497.

A JET OF STEAM

Its Velocity — How great?
How utilized? How acquired?

RESEMBLES A CROWD LEAVING A BALL GAME

THE wheel of a De Laval steam turbine runs at about thirty thousand revolutions per minute, which, if the wheel is 6 inches in diameter, makes the velocity of the ends of the turbine blades about 780 feet per second. As the speed of the blades is about one-half that of the steam driving them, this means that the jet as it leaves the nozzles just before hitting the blades must be traveling at a velocity of about 1500 feet per second.

It can easily be shown that if steam is taken from a boiler at high pressure and is permitted to expand freely through a nozzle down to a pressure of one pound per square inch it will develop, if unopposed, a velocity of 3000 to 4000 feet per second or from 35 to 45 miles a minute, depending upon its initial condition.

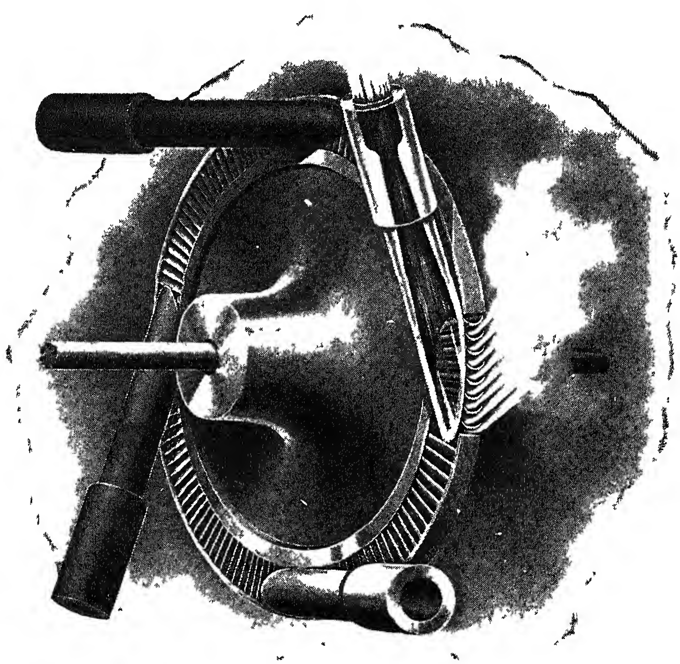
This velocity is so tremendous that it cannot be utilized in a single turbine wheel as it is not safe to run turbine wheels as fast as one-half this velocity for fear they would fly apart. Turbines of this type are, therefore, used only for small pressure ranges which give relatively small jet velocities.

The best way to appreciate how great is the velocity of a steam jet is to compare it with velocities developed in other ways. The following table contrasts the velocity of the steam jet with the velocity of water jets, of steam through pipes, of trains, of falling bodies, and of bullets leaving the nozzles of various rifles, of molecular vibrations, of the movements of celestial bodies, of ether vibrations, etc.

TABLE OF VARIOUS VELOCITIES

	Feet Per Second	Miles Per Minute
Steam trains	30 to 100	0.3 to 1.2
Steam through steam pipe	100 to 200	1 to 2
Water from nozzle under 100-ft. head	80	.9
Dart dropped from airplane one mile in air (mighty air friction) at moment of striking	580	6.6
Sound wave through the atmosphere	1100	12–13
Equatorial velocity of earth due to daily rotation	1520	17.3
Bullet from sporting rifle	2500	30
Bullet from German rifle (Mannlicher)		
Maximum velocity	3750	45
Ordinary velocity	2750	
Bullet from Canadian rifle (Ross)		
Maximum velocity	4200	47¾
Ordinary velocity	3150	
Saturated steam expanding through nozzle from 250 lbs. to 1 lb.	4200	47¾
Superheated steam from 600 lbs. and 625° F. to 1 lb.	4700	53.4
	Miles Per Second	
Body falling from space upon moon due to moon's attraction	1.7	102
Probable maximum velocity of molecules at 32° F.		
Carbon dioxide	1.6	96
Oxygen	1.8	108
Nitrogen	2.0	120
Water	2.5	150
Hydrogen	7.4	444
Body falling from space upon earth due to earth's attraction	7.3	438
Average velocity of earth about sun	19	1140

Water from a nozzle under a 100-foot head travels about as fast as an express train, while steam flowing along a pipe from a boiler toward the engine travels at about twice the speed of an express train. A dart dropped from an airplane one mile in the air has, at the moment it strikes the earth, a velocity of about $6\frac{2}{3}$ miles per minute, but this in turn is only about one-half that with which sound travels through the atmosphere. The ordinary sporting rifle imparts to the bullet a velocity nearly $2\frac{1}{2}$ times that of a sound wave, or about $1\frac{2}{3}$ times that of a point on the earth's equator, due to its daily rotation. The highest observed velocity obtained by a German rifle (Mannlicher) is 50 per cent greater than this, or 45 miles per minute. The highest velocity ever reached in a sporting rifle was that developed by a Canadian rifle (Ross), which was $47\frac{3}{4}$ miles per minute. Both these values are, however, not attained under ordinary conditions. If steam from a boiler at 250 pounds pressure expands through a turbine nozzle down to one pound pressure, it develops in the short distance of a few inches (the length of the nozzle) as high a velocity as that of a Ross rifle bullet, or $47\frac{3}{4}$ miles per minute. Some boilers are now designed to run with steam at 600 pounds pressure, superheated various amounts. Assuming such steam at a temperature of 625° F. to be permitted to expand down to one pound pressure, the jet on issuing from the nozzle would, neglecting friction loss, have a velocity of nearly $53\frac{1}{2}$ miles per minute. This, apparently, is the highest velocity attained by bodies whose motions are to a certain extent controlled by man and is exceeded only by that of molecules, and celestial bodies, and ether vibrations.



THE DE LAVAL TRADE MARK, ILLUSTRATING THE PRINCIPLE OF THAT INVENTOR'S STEAM TURBINE

The method of calculating the velocity of a jet of steam is very similar to that used in calculating the velocity of a jet of water, and the underlying phenomena can be understood in both cases even if the calculations do require a considerable knowledge of physics and mathematics.

As the simplest illustration of the flow of fluids, we have the case of water escaping through an orifice at the bottom of a tank. Here the water is forced out by

the weight of the liquid back in the tank; and, as can be readily shown, if it were not for friction losses, the velocity of the jet of water would be exactly the same as that of a freely falling body dropping through the same distance. In this case, there is no appreciable expansion of the water, so that its onward motion is due solely to the push of the water behind, *i.e.*, to the head acting on the orifice. In the case of the escape of steam, compressed air or any other expansable fluid, the flow is not only due to the push of the gas behind the orifice, but also to the expansion of the gas itself, as its molecules recede from one another during its flow through the orifice. Therefore, the velocity of a jet of steam cannot be calculated as easily as can that of a jet of water because the energy producing it is not simply the pull of the earth, or the gravitational head impelling the water forward, but it is due to the pressure of the fluid plus the internal energy liberated by the substance itself, as it expands. If, however, we take the sum of these two energies, that due to the work delivered by the fluid behind the moving portion plus the energy due to its state of molecular activity and call their sum the total energy head, then the equation for the velocity of flow has the same general form as that in the case of water. Thus for water, the

$$\text{Velocity} = \sqrt{2\,g\,(h_1 - h_2)},$$

where $h_1 - h_2$ is the decrease in the gravitational head as the water moves nearer the center of the earth. In the same way the velocity of a jet of steam, or air, can be calculated from the formula

$$v = \sqrt{2\,g\,(i_1 - i_2)},$$

where $i_1 - i_2$ represents the decrease in the total energy available for moving this fluid. Engineers have charts and tables which enable them to read directly the values of the total energy of the steam for any given conditions.

The great differences in the velocities of moving jets of water and steam naturally occasion a corresponding difference in the type of turbine wheel impelled by such jets. The theory of turbines teaches that the velocity of the blades on which the jet impinges should be something less than one-half the velocity of the jet itself. In the case of water turbines this gives a very moderate velocity for the circumference of the wheel, but in the case of steam turbines it may mean that the blades of the rotor travel at velocities of 500 or 1000 feet per second so that great care must be taken in the design of the machine and choice of materials to prevent disruption at such high angular velocities.

The energy possessed by a traveling body is easily calculated from the equation

$$\text{Kinetic energy} = \frac{\text{weight}}{64.3}\,(\text{velocity in feet per sec.})^2$$

Thus a pound of steam traveling at 1000 feet per second possesses an amount of energy equal to 15,550 foot pounds. The energy possessed by a rapidly moving jet of steam can be utilized to perform work provided the jet is made to impinge upon some moving substance such as a turbine wheel, or a stream of water in an injector, or low temperature steam drawn from a condenser. In all cases, the jet of steam is slowed down, thereby losing part of its kinetic energy, which is transmitted to the body impinged upon.

The utilization of a jet of steam to propel a stream of water is illustrated in the action of the ordinary steam injector used for pumping feed water into boilers. In these instruments steam passes through a nozzle designed to permit it to attain an exceedingly high velocity and so situated that the issuing jet of steam enters directly into the middle of a cone of water supplied through a suction pipe. As both the rapidly moving steam jet and the slow moving cone of water are traveling in the same direction, the result of the impact is that the steam is slowed down and the water accelerated and there is produced from the admixture of the steam and the cold water a stream of hot water which travels on with an intermediate velocity. This velocity is sufficient to overcome a greater static head of water than that corresponding to the pressure in the boiler from which the steam has been taken, or even a much

higher pressure. At first sight, such action seems almost impossible, as one would expect hot water to be blown out of the boiler with a velocity equal to that of the steam. But we have to remember that the water, if it did not partially vaporize and thus increase in volume, could simply be forced out with a velocity equal to that due to a head that would create as much pressure as the steam pressure in the boiler, while the steam which leaves the steam space under the impetus of this same boiler pressure acquires additional velocity due to the utilization of its own internal energy as it expands through the steam nozzle inside of the injector. The steam jet thus has a velocity many times greater than that which would be possessed by a jet of hot water blown out of the same boiler under the action of the pressure alone. A pound of steam possesses enough energy to carry 10 or 15 pounds of cold water along with it into the boiler, the amount of water naturally varying with the amount of kinetic energy possessed by the steam.

Naturally steam which comes out of a boiler cannot force itself back again as steam, as then the amount of work required to compress it from low pressure back to high pressure, and undo the expansion that has just taken place in the nozzle, would be equal to that developed in the nozzle, even provided there were no friction loss. The only way that the steam can force itself back into the boiler is to decrease the amount of work required for this process and this is accomplished automatically when the steam is condensed by mingling with the water in the injector, thus diminishing the volume to be forced back into the boiler.

The action of steam in utilizing its internal energy while expanding might be likened to that of a large number of compressed springs piled one above the other when the restraining force is removed. Thus suppose the bonds confining the upper one to be loosened, the top of this spring would move forward suddenly and would lift a weight remaining upon it. Again, suppose that the bonds confining all the springs had been loosened simultaneously, then any one spring in the pile would move upward not only because of its own expansion, but also because of the expansion of the springs below it. Each spring in being lifted up will have work done upon it by those underneath and it, in turn, would help to lift the springs above it not only due to this work, but also due to its own expansion.

The action of steam expanding through an opening is, in a certain sense, similar. If an opening is made in the side of a boiler all the steam in the boiler will begin to flow toward it; the steam farthest away moving slowly, that nearer the opening with ever increasing velocity, due not simply to the push of the steam behind, but also to its own expansion. The steam in the opening will be pushed forward very rapidly by the general expansion of the steam behind it, and because of this, together with the effect produced by its own rapidly increasing volume due to the decreasing pressure to which it is subjected, it eventually will enter the atmosphere at a very high velocity.

Another analogy may serve to throw light on the action of such a jet of steam. At the close of a ball game the spectators converge slowly from all parts of the field towards the gate, individuals jostling one another and interfering with one another's lateral motion but gradually acquiring more rapid forward motion until, as they pass through the gate, they separate — expand, as it were — and the crowd spreads out, many even running to escape the pressure of those behind. If the opening through which the steam passes is made with a converging portion leading to the throat section and a flaring portion leading away from the throat, then the passage of a stream of steam molecules through such a nozzle is somewhat analogous to this. Due to the constricted throat section of a nozzle, molecules jostle one another as they pass through the reduced area into the throat, and to a certain extent impede one another's lateral motion. The molecules continue to fly apart, the volume of the gas increasing, and the whole mass hurries away with rapidly increasing velocity as it progresses along the nozzle.

IN THE BOWELS OF THE EARTH

The World's Impressive Subterranean Hollowings and Cavernous Waterways

A DUSTLESS AND GERMLESS UNDERWORLD

LET us now consider the subject of caves. Though caves have not the grandeur of waterfalls, they have always appealed to the imagination of men. There is room in their shadowy grottoes for many dreams and many mysteries, for sibyls and nymphs, for fairies and gnomes, for Typhon and Cyclops. From caverns spake the oracles of Corinth and Delphi; into a cavern in a hill did the Pied Piper lead the dancing children; and a cavern in the hills of Granada still hides Boabdil and his Moors. But caves have appealed not only to the imagination, but also to the practical instincts of men; they have been used from time immemorial as dwelling-places, as fortresses, and as tombs. Lot went up from Zoar and dwelt in a cave, he and his two daughters; in caves kings of Canaan and kings of Scotland, freebooters, smugglers and martyrs have found refuge from their foes. In a cave good Obadiah concealed a hundred prophets; in a cave Joshua imprisoned five kings. In the cave of Machpelah sleep Abraham and Sarah, Isaac and Rebecca, Jacob and Leah, and Joseph.

It is probable that whole races of Palæolithic men dwelt in caverns, kindling fires, cooking food, sharpening their flints there and drawing pictures of mammoths and bisons on the cave walls. In Neolithic days multitudes of men inhabited caves, and much of our knowledge of early man is derived from a study of the contents of such rocky chambers. Even now in parts of France, Spain and Italy cave-dwellers are to be found, and in the Canary Islands, within a stone's throw of modern hotels, natives still live in caves.

Burial caves, like dwelling caves, are found all the world over, and, like dwelling caves, have done much to throw light on the ways of primitive man. In the cave of Itruipe, in South America, Humboldt counted 600 skeletons and mummies preserved in baskets woven from the petioles of palm-leaves. Along with the skeletons and mummies were found sandals, implements and ornaments. In burial caves in the Aleutian Islands, Mr. W. H. Dall, paleontologist of the U. S. Geological Survey, found mummies in a sitting posture which had been most carefully wrapped in fine woven grass ornamented with tufts of feathers and reindeer hair, surrounded by a coarser covering and overlaid with a coat made of bird skins. These bundles were again packed in dried grass, covered with large otter skins and made secure with a braided network of twisted sinews. Beside the mummies were found masks and effigies, awls and needles, axes and arrows. In a cave in Teneriffe were found more than a thousand mummies, which had been embalmed, sewn up in goatskins, and bound with leather.

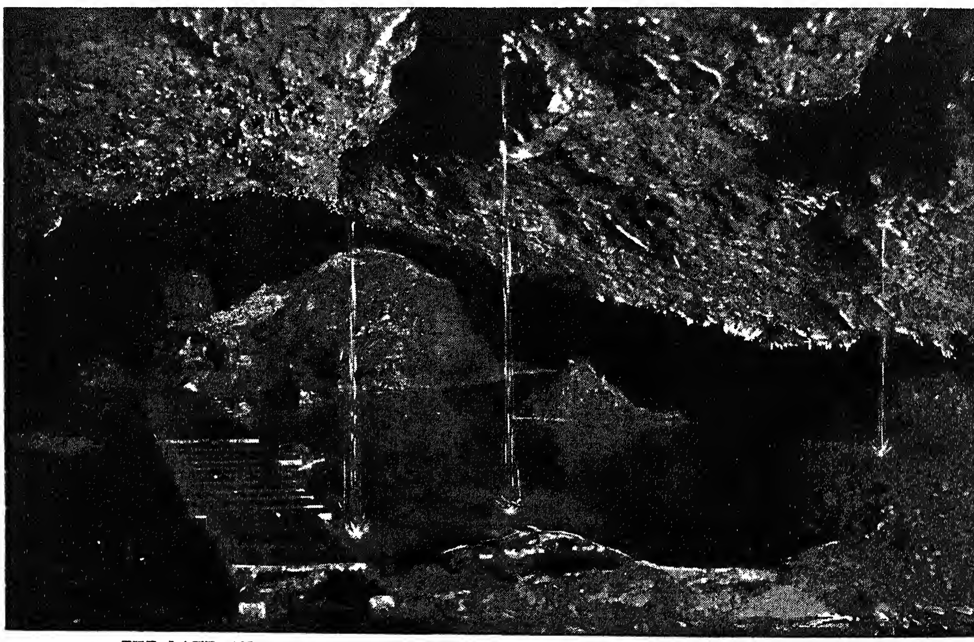
Many caves, known as "bone caves", are notable chiefly for the bones of animals which they contain, and the light they thus throw on the biological history of the country. In a cave in Yorkshire, England, Buckland discovered teeth and bones of no less than twenty-three species of animals — hyena, tiger, bear, fox, weasel, elephant, rhinoceros, hippopotamus, horse, ox, deer, hare, rabbit, water-rat, mouse, raven, pigeon, lark, duck. In the Wookey Hole, near Wells, England, have been found those of grizzly bear, fox, woolly rhinoceros,

great urus, reindeer, cave-lion, brown bear, badger, bison, red deer, cave-bear, wolf, mammoth, horse, Irish elk, lemming and, last but not least, man

The bone caves of Belgium are particularly rich in animal relics That at Lunal-Viel, for instance, contains nearly one-half of all the hundred-odd species that have been discovered in caves In the Gailenreuth Caves, in Franconia, bones of no less than 800 bears were found In the Neanderthal Cave near Dusseldorf was found the famous so-called "Neanderthal" skull — a human skull of very great antiquity. The caves in North America that have yielded animal remains, such as Port Kennedy and Frankstown, Pennsylvania, according to Scott, are hardly caverns in the ordinary sense of the word, rather narrow fissures into which bones and carcasses were washed by floods.

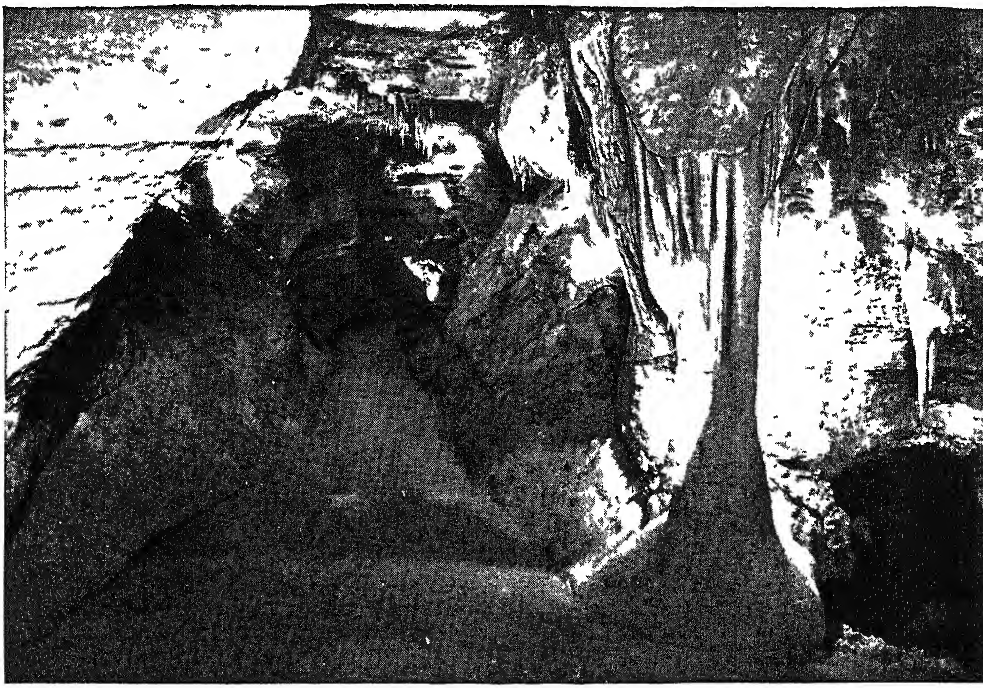
Caves have also preserved for us examples of the dawn of art. In the Pyrenees, the Cave of Murat, lately explored by the Abbé Lemozi, was so rich in pictures and graving tools that it was believed to have been the dwelling place of a family of professional artists of the Stone Age. In September, 1923, the same Abbé reported the discovery of a great gallery some 340 feet long and 35 feet wide on the walls of which are painted and engraved, in red and black, pictures of forty prehistoric animals.

Caves originate in various ways — they may be volcanic in their origin; they may be excavated by the sea or by subterranean streams and rivers Volcanic caves may be made in the crust of the earth simply by ejection of lava In a single eruption a volcano may pour out millions of tons of lava, and, naturally, the ejection of this large amount of material must leave holes in the crust. Or they may be made in the lava itself by the shrinkage of its interior. Such "lava caves" are often of considerable size. There is one near the base of Monte Rossi about a mile long; and Professors Brewer and King explored a lava cave on the flank of Mount Shasta half a mile long, whose sides were dimpled with blister-holes and lined with lava-froth. The finest lava caves in the world are found in Iceland, and the finest of the Icelandic lava caves is the Surtsheller. The tremendous eruption of Skaptar Jökull in



THE LAKE AND ITS ISLAND IN WOOKEY HOLE CAVE, NEAR WELLS, ENGLAND

1783 spread a torrent of lava over an area of 420 square miles, and in the center of this enormous mass of lava is the Surtsheller lava cave. The cave is named after Surt, the Prince of Darkness of the Scandinavian mythology. It is entered through a chasm in the lava, and is about a mile in length, and for nearly 4000 feet is 40 feet high and 50 feet wide. Dr. Ebenezer Henderson, who explored the cave first, nearly a hundred years ago, says that: "The roof and sides of the cave were decorated with the most superb volcanic icicles, crystallized in every possible form, many of which rivaled in minuteness of beauty the finest zeolites, while from the floor rose pillars of the same substance, assuming all the curious and fantastic shapes imaginable, mocking the proudest specimens of art and counterfeiting many well-known objects of animated nature. Many of them were upwards of four feet high, generally sharpened at the extremity, and about two feet in thickness. A more brilliant scene never presented itself to the human eye, nor was it easy to divest ourselves of the idea that we actually beheld one of the fairy scenes depicted in Eastern fable."



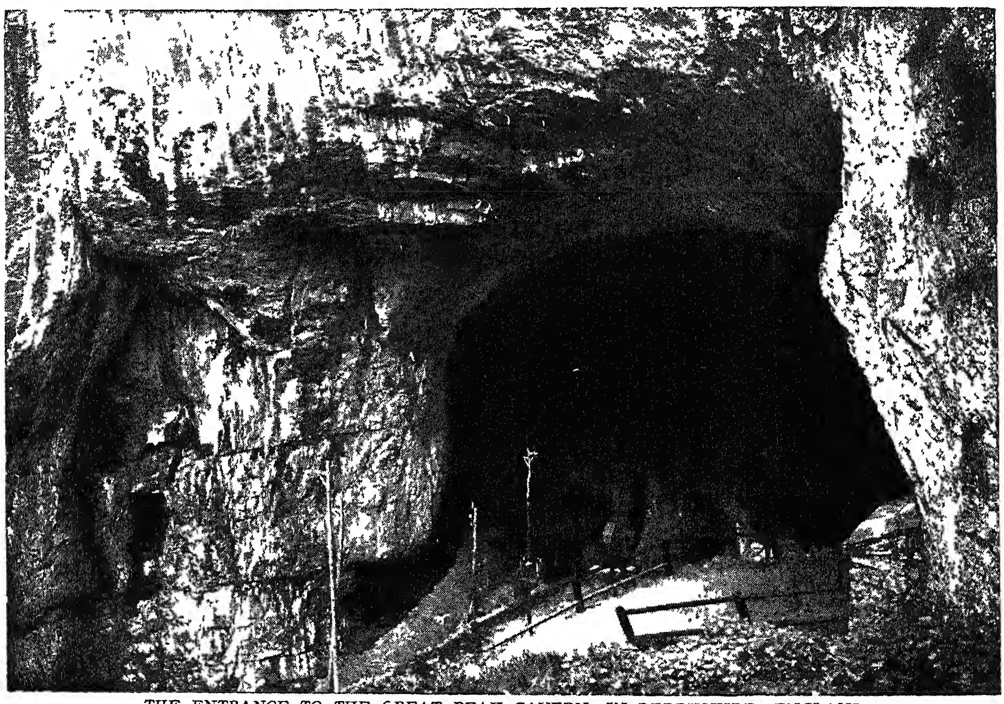
VALLEY OF DREAMS, CAVE OF THE WINDS, COLORADO

Marine caves made by the eroding action of the sea are very numerous. The most typical are made not in soft but in hard rocks, such as basalt. The soft rocks are broken down altogether; but the hard rocks are more resistant, and are eroded chiefly where there happens to be weaker spots in their armor. The high granite cliffs of Sark, one of the Channel Islands, are honeycombed by caves, as are also the rugged coasts of Norway. One of the best specimens of a marine cave is found in Fingal's Cave, on the island of Staffa, off the northwest coast of Scotland. It appealed to Scott as a place

Where as to shame the temples decked
By skill of earthly architect
Nature herself, it seemed, would raise
A minster to her Maker's praise!
Not for a meaner use ascend
Her columns or her arches bend;
Nor of a theme less solemn tells
That mighty surge that ebbs and swells,
And still, between each awful pause,
From the high vault an answer draws,
In varied tone, prolonged and high,
That mocks the organ's melody.

The island of Staffa is a mass of igneous rocks, and around its coasts are grouped immense basaltic pillars. Strong and hard though the pillars be, the sea has eaten into them in places, and hollowed out seven caves. The most remarkable of these is Fingal's Cave. It is 227 feet long, 42 feet broad, and 66 feet high, and 25 feet deep at ebb. The arched entrance is 33 feet wide and 65 feet high. It is not a large cave as caves go, but its boast is its architecture, not its size. Its roof is supported by ranges of great basaltic pillars about two feet in diameter, and having five or six sides, and both roof and floor show sections and stumps of columns that have been broken away by the sea. There is not "a single stone or fragment which is not prismatic, and symmetrically, perfectly and regularly sculptured". Walls and roof, too, are beautifully polished, and reflect in places bright orange and emerald tints, which give varied beauty to the twilight in the interior of the cave. The Celtic name of the cave means "harmonious grotto", for the sea winds and sea waves harp on the great columns and make a low, sweet harmony.

We now come to the most interesting class of caves — those excavated in limestone rock by subterranean water. Anyone who has noticed the corrosive effect of the dripping of a siphon of carbonated water upon a marble slab will readily understand how underground water, impregnated as it always is with carbonic acid, must in time corrode caves in the limestone rock. These caves depend for their beauty chiefly on their stalagmites and stalactites, the calcareous growths formed by the limy water dripping from their roofs and walls. The water carrying limestone in solution as the bicarbonate drops from crevices in the roof; as it evaporates, the bicarbonate breaks down, carbonic acid is freed and the calcium carbonate crystallizes in icicle forms, giving the stalactites. The ground splash, evaporating similarly, makes the stalagmites which grow upward to meet their pendent parents. The most remarkable of these limestone caverns are the Adelsberg Grotto, in Carniola, and the Aggtelek Cave, in old Hungary. The former, including its ramifications, is over five miles in extent, and disputes with the Aggtelek the

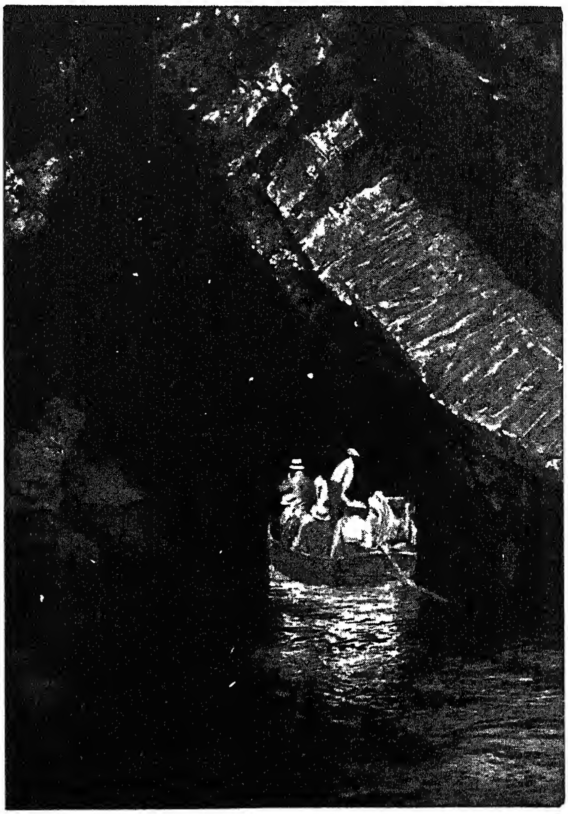


THE ENTRANCE TO THE GREAT PEAK CAVERN, IN DERBYSHIRE, ENGLAND

title of the longest in Europe. It has been explored for more than two miles, and the River Poik, which penetrates it, can be followed for half a mile. The cavern expands here and there into chambers, and the largest of these, the Franz Joseph and Elizabeth Grotto, is 223 yards long and 214 yards broad. W. H. Davenport Adams says, "There is not, perhaps, another cavern in the world so distinguished by a character of grandeur and boldness. The irregularities of its surface, the fissures torn in its vast sides, its deep shadows and gloomy hues, form a striking contrast with the regular beauty and symmetrical grace of the whitely gleaming and transparent concretions suspended from the roof, and reflecting in all directions the flashing light of torch and taper."

In the cave is found the curious eel-like animal called Proteus, which having gills and lungs, can live under water and in air.

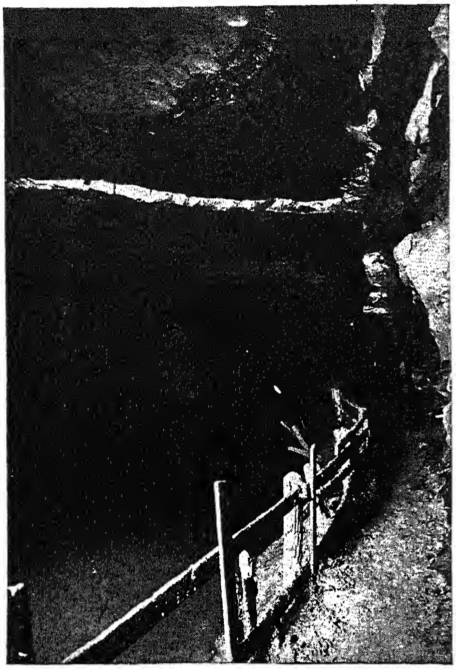
There are no other caverns in Europe so large as those just mentioned, but there are many more beautiful. France has the Grotto of La Balme, the Grotto des Demoiselles, the Grottoes of Arcy and the Grottoes of Osselle, all adorned with fantastic and beautiful stalagmites and stalactites. In Belgium we may visit the wonderful Grotto of Han-sur-Lesse. Greece boasts of the Grotto of Antiparos, situated on the Island of Antiparos, which many consider the most beautiful stalactitic cavern in the world. It contains a superb stalagmite, 24 feet in height and about 20 feet in diameter at its base, which is known as "The Altar", since Mass was celebrated upon it in 1673.



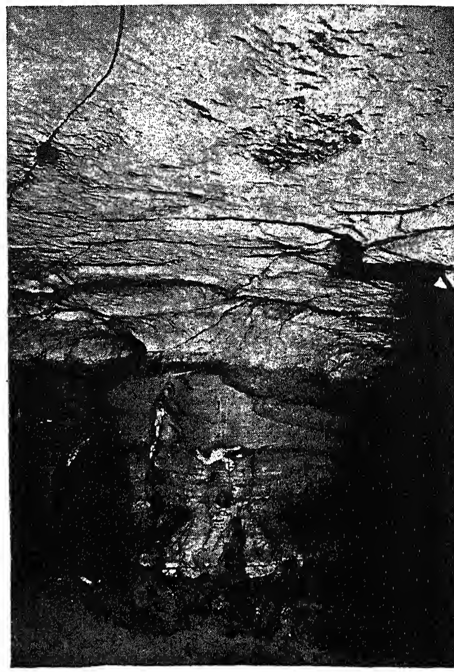
THE GROTTO AT MORGAT, BRITTANY

One of the great limestone caves is the Mammoth Cave, in Kentucky, with more than 200 known avenues, of an average width and height of seven yards, and of a total length of over 100 miles, representing an erosion of 12,000,000 cubic yards of limestone. A French traveler making a tour of the world declared that no spectacle, not even Niagara Falls, impressed him so much as this cave. Bayard Taylor said: "It is the greatest natural curiosity I have ever visited, Niagara not excepted; and he whose expectations are not satisfied by its marvelous avenues, domes and sparry grottoes must either be a fool or a demigod."

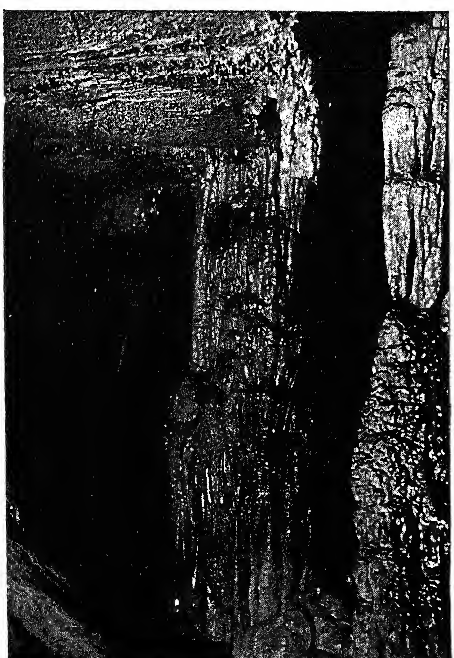
Naturally, in a cave of this size there are many large rooms; about fifty-seven are known, and each has been given a distinctive name, such as the Gothic Church, Bacon Chambers, Ole Bull's Concert Room, Mary's Bower, Mary's Vineyard, Lucy's Dome, the Star Chamber, etc. The largest chamber, named the Chief City, is 450 feet long and 130 feet wide Some of the Chambers are very lofty, the Stella, Mammoth and Gorin's domes are about 250 feet high, and Lucy's Dome is over 300 feet high. The Cleveland Avenue is 60 feet wide, 20 feet high and two miles long. Bayard Taylor's description of the mighty cavern may well be quoted here:



ECHO RIVER

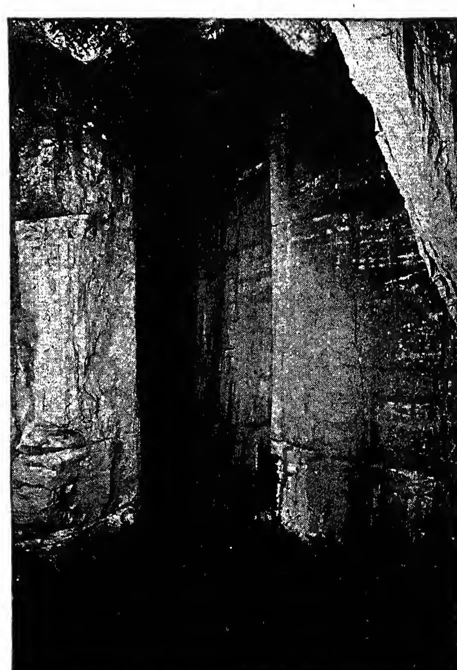


DIVIDING OF THE WAYS



Photos Brown Bros.

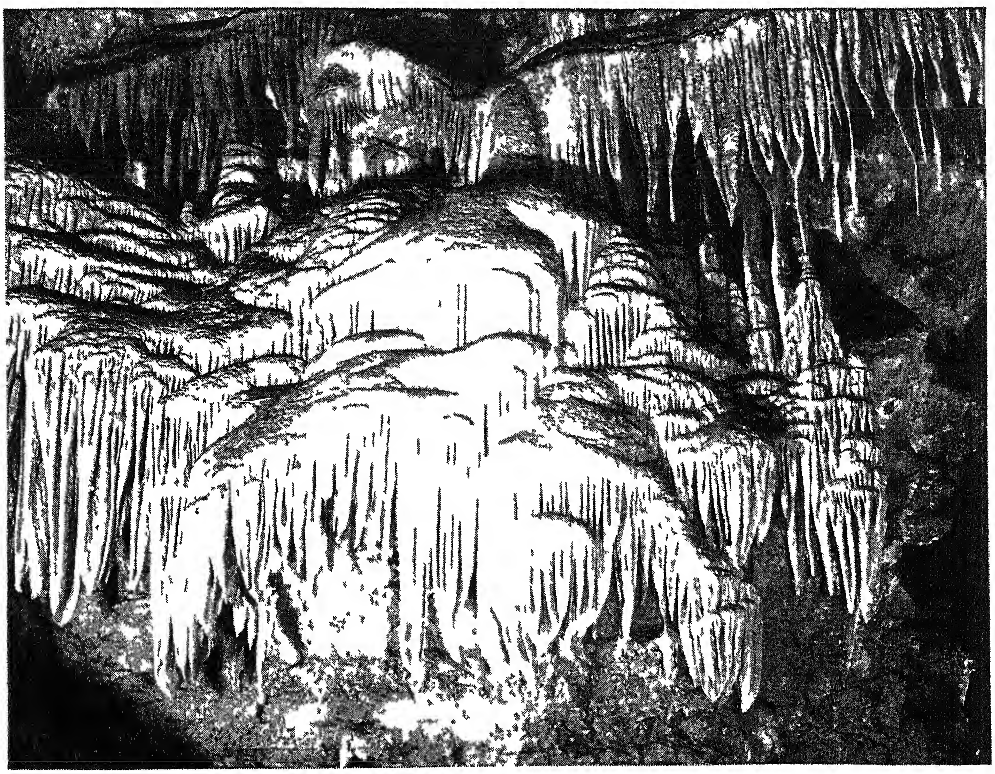
POMPEY'S PILLAR



MAMMOTH DOME

"We first entered the Snowball Room, where the gnome children in their sports have peppered the grey walls and ceiling with thousands of snow-white projecting discs so perfect in their fragile beauty that they seemed ready to melt away under the blaze of your lamp. Then commences Cleveland's Cabinet, a gallery of crystals the richness and variety of which bewilder you. It is a subterranean conservatory filled with the flowers of all the zones, for there are few blossoms expanding on the upper earth but are mimicked in these Gardens of Darkness. I cannot lead you from niche to niche and from room to room examining in detail the enchanted growths; they are all so rich and so wonderful that the memory does not attempt to retain them. Sometimes the hard limestone rock is changed into a parterre of white roses; sometimes it is starred with opening daisies; the sunflowers spread their flat discs and rayed leaves; the feathery chalices of the cactus hang from the clefts; the night-blooming cereus opens securely her snowy cup, for the morning never comes to close it; the tulip is here a virgin, and knows not that her sisters above are clothed in the scarlet of shame.

"In many places the ceiling is covered with a mammary crystallization, as if a myriad bubbles were rising beneath its glittering surface. Even on this jeweled soil which sparkles all around you grow lilies and roses, not singly overhead, but clustering together towards the base of the vault, where they give place to long, snowy pendulous cactus flowers, which droop like a fringe around diamonded niches Here you see the passion flower, with its curiously curved pistils; there an iris with its lanceolate leaves; and again bunches of celery with stalks white and tender enough for a fairy's dinner. There are occasional patches of gypsum, tinged a deep amber color by the presence of iron. Through the whole length of the avenue there is no cessation of the wondrous work.



TITANIA'S VEIL, CAVERNS OF LURAY, VIRGINIA

The pale rock-blooms burst forth everywhere, crowding on each other until the brittle sprays cannot bear their weight, and they fall to the floor. The slow, silent efflorescence still goes on as it has done for ages in that buried tropic." In Mary's Vineyard the stalactites take the form of clusters of luscious grapes burdening hundreds of dewy boughs. The Star Chamber is named from its starry roof, black with binoxide of manganese and studded with snowy points of calcite gleaming like stars in a moonless sky of midnight black.

Besides these chambers, the Mammoth Cave contains eleven lakes, seven rivers, eight cataracts and thirty-two abysses. Lake Lethe is a body of water about 400 feet long and 40 feet wide, and the River Styx has about the same dimensions. Echo River is from 20 to 200 feet wide, and about three-quarters of a mile long and communicates with Green River through a subterranean passage. The extraordinary echoes produced by agitating the water with the boat's paddle are particularly beautiful "The first sound that broke the stillness was like the tinkling of silver bells. Larger and heavier bells then seemed to take up the melody, as the waves sought out the cavities in the rock. And then it appeared as if all chimes of all cathedrals had conspired to raise a tempest of sweet sounds. They then died away to utter silence. We still sat in expectation. Lo, as if from some deep recess which had been hitherto forgotten, came a tone, tender and profound; after which, like gentle memories, were reawakened all the mellow sounds that had gone before, until River Hall rang again."

It might be thought that the air in these deep recesses must be impure and heavy, but, on the contrary, it is exceptionally pure and exhilarating.

The Cave of the Winds is situated near the head of Williams Canyon, two miles north of Manitou Springs, Colorado, at the foot of Pikes Peak, elevation 7,000 feet. Nature was generous with her decorations of the many rooms and passages with ornaments of stalactites, helictites, ribbons, and small delicate growths hanging from the ceilings; the walls being adorned with curtains, draperies and cascades of flowstone. The first level goes directly into the Curtain Room, Canopy Hall, Boston Avenue, and Reception Room. The second level has its Manitou Dome, Lovers' Lane, Majestic Hall, Crystal Palace, Findlay Alcove, Old Curiosity Shop, Valley of Dreams and the Mysterious Temple of Silence. The third level leads to the Bridal Chamber, Coral Dome and the Old Maid's Kitchen.

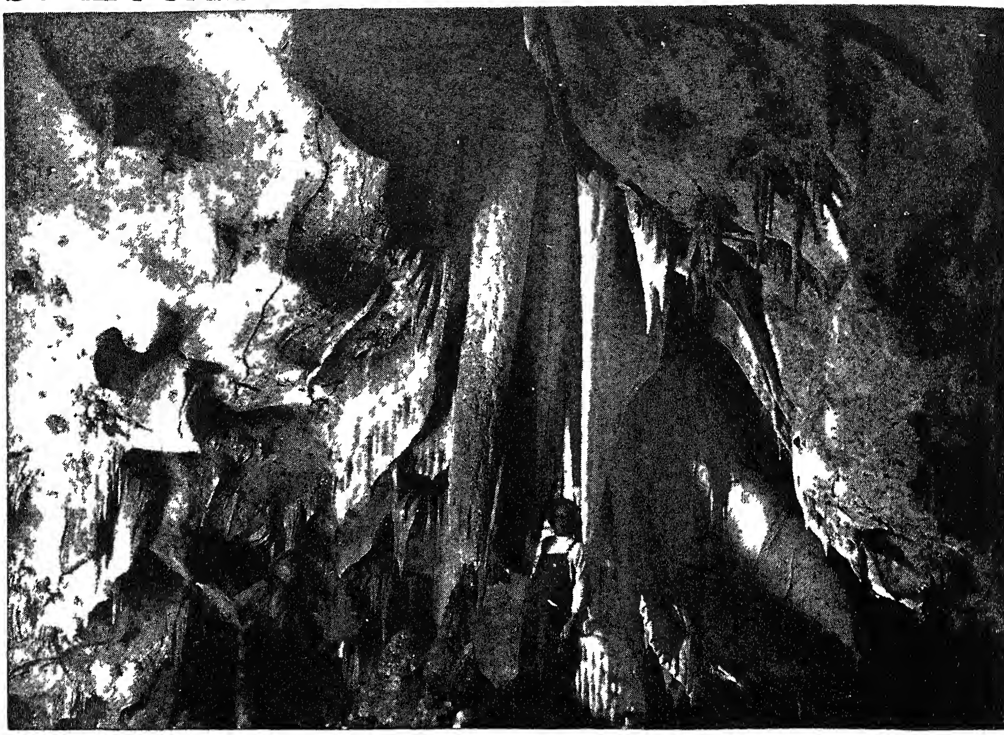
One of the largest caves in the world is the Wyandotte Cave, in Indiana, and, like the Mammoth Cave, it occurs in a limestone region. It has over twenty-three miles of avenues, and, though not so large as the Mammoth Cave, is in some respects more beautiful, and is said to have a greater number and variety of stalactites than any other cave in the United States. Its chief marvel is the "Pillar of the Constitution", a column of oriental alabaster 40 feet high and 75 feet in circumference. The temperature of the cave is the same as that of the Mammoth Cave.

A very beautiful cavern is found at Luray, in Page County, Virginia. At some time, long after its original excavation, it must have been scoured with acid-charged glacial mud which eroded the already formed dripstone into beautifully grotesque shapes. Its stalactitic display is probably the finest known. In the canopy above the "Imperial Spring" no fewer than 40,000 stalactites are to be seen. The Swords of the Titans are 50 feet long and 3 to 8 feet wide, and when struck by the hand give forth sounds like tolling bells. Brand's Cascade is a mass of alabaster like a frozen cataract. "Imagine, if possible," says Hovey, "a great cataract of milk 30 feet wide and 40 feet high, rushing and copious, suddenly caught in mid-air and polished to a wax-like luster. And beyond it another smaller one, as yellow and golden as liquid amber. And then fancy this whole shining and glorious mass flooded by the dazzling brilliancy of electric lamps, and confess that it must rival the most wonderful scene ever pictured by pencil or pen!"

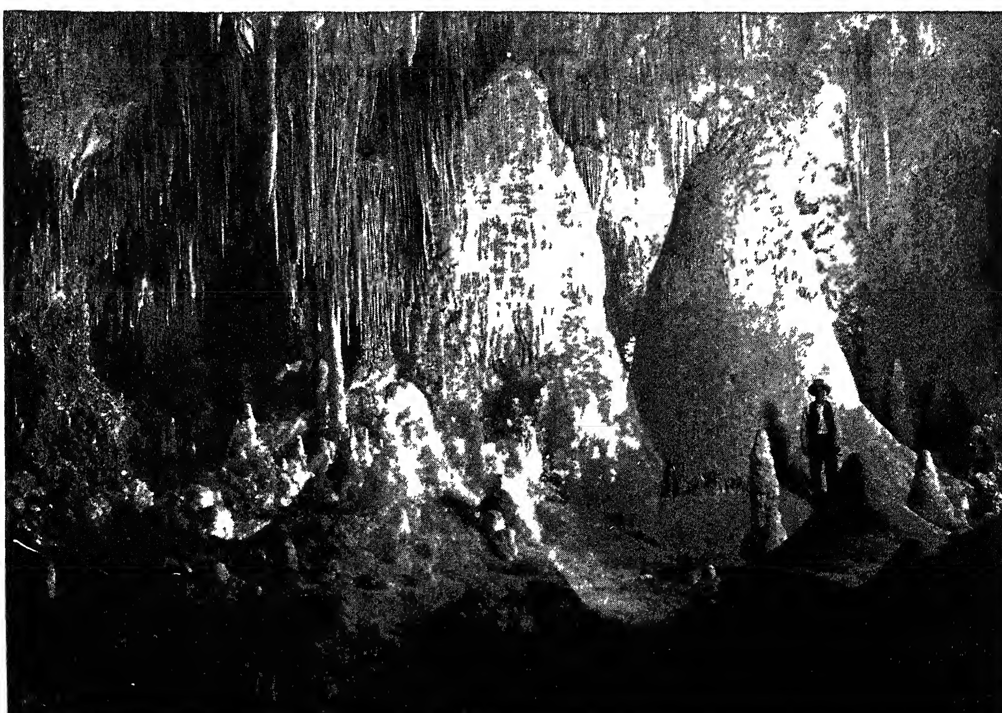
IN AN INDIANA CAVERN

Acme

Clusters of stalactites and stalagmites in Wyandotte Cave, Indiana. A stalactite is a deposit of calcium carbonate, hanging like an icicle from the roof or sides of a cavern. A stalagmite is formed on the floor of a cave by the drip of calcareous (calcium-bearing) water from the roof.

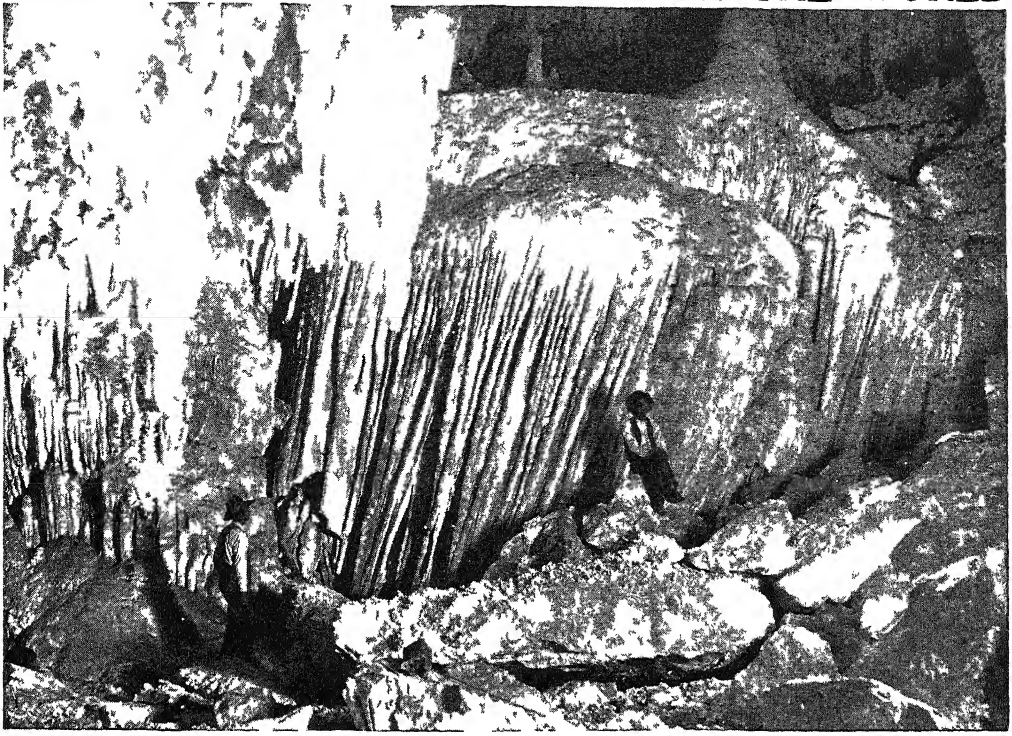


THE ELEPHANT'S EAR IS ONE OF THE ANIMAL-LIKE REPRODUCTIONS



Wide World Photos

OPENINGS IN THE WALLS OF VARIOUS CHAMBERS ARE CONCEALED WITH DAINTY DRAPERIES

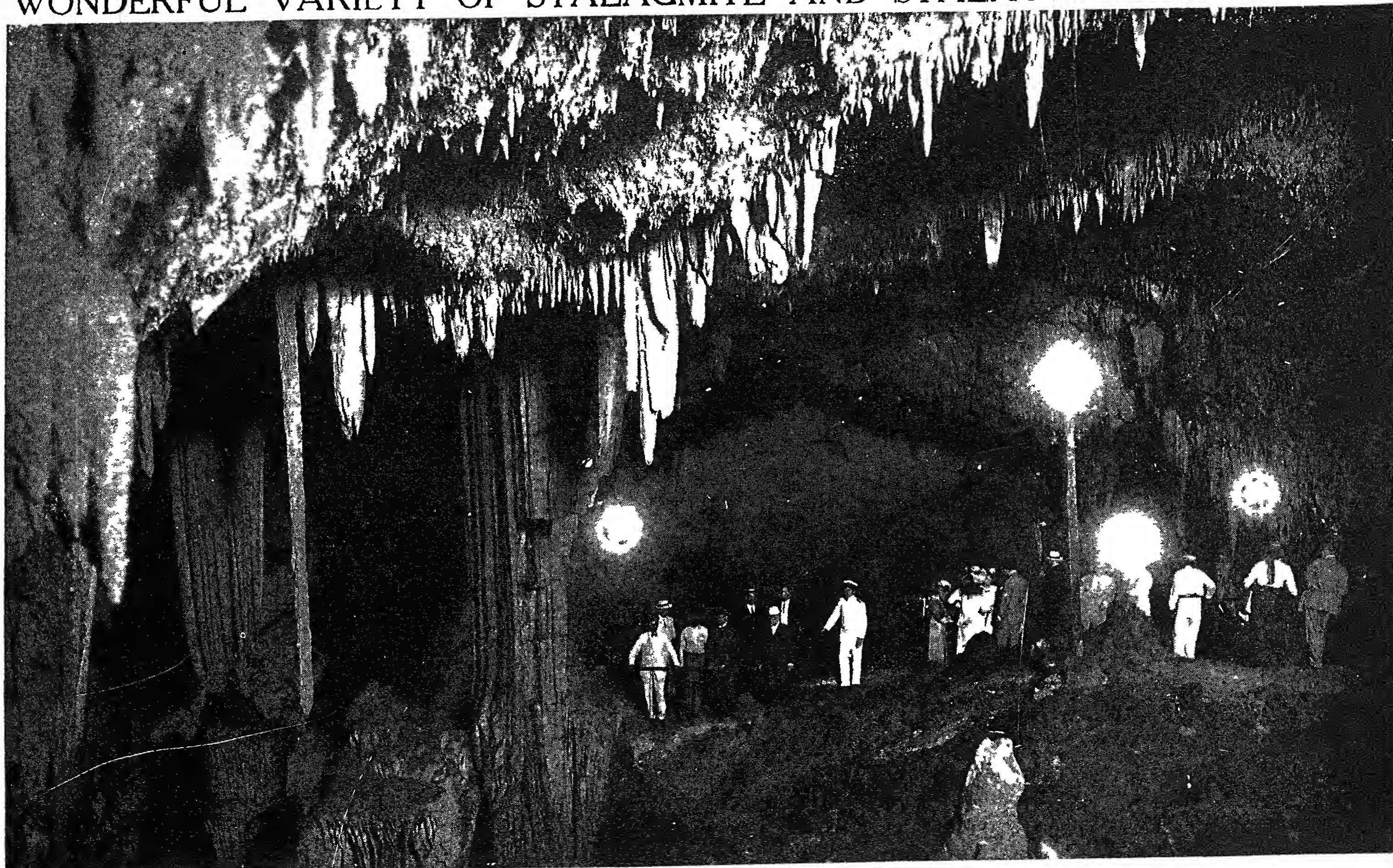


SNOW WHITE FORMATIONS THAT SUGGEST THE FROZEN NORTH

Wide World Photos

SOME OF THE DELICATE INTERIOR DECORATIONS LAVISHED BY NATURE

WONDERFUL VARIETY OF STALAGMITE AND STALACTITE FORMATIONS

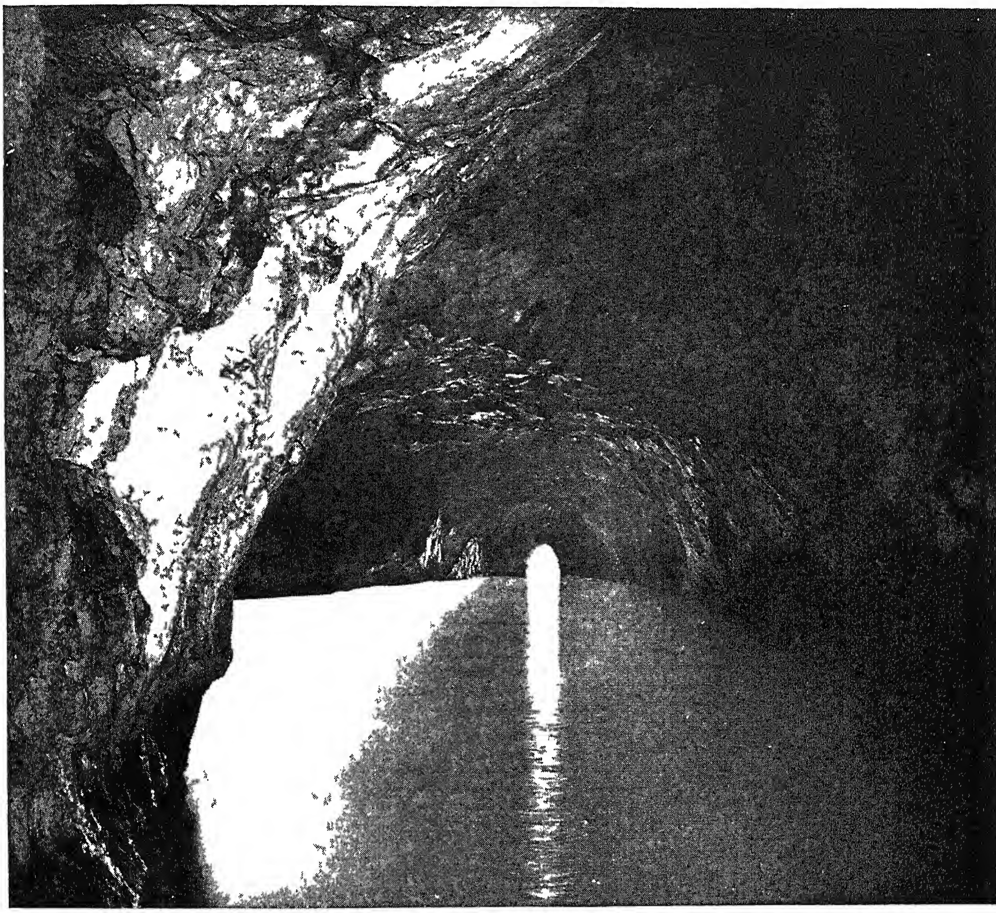


IN THE BELLAMAR CAVES MATANZAS, CUBA

The temperature of the Luray Cavern is about 54° F, and the air is germless and almost optically pure The Blue Grotto of the island of Capri, pictured on this page, deserves mention not for its size but for the interesting phenomenon to which it owes its name This limestone cave, somewhat elliptical in form, a result of chemical and wave erosion, is about 1300 feet in circumference, the roof being 41 feet above the water The sea flowing through the only entrance is 48 feet deep in the cave When the sun shines outside, the light penetrating the water and reflected up into the cave gives everything, water, rocky walls and bristling stalactites, a beautiful blue color.

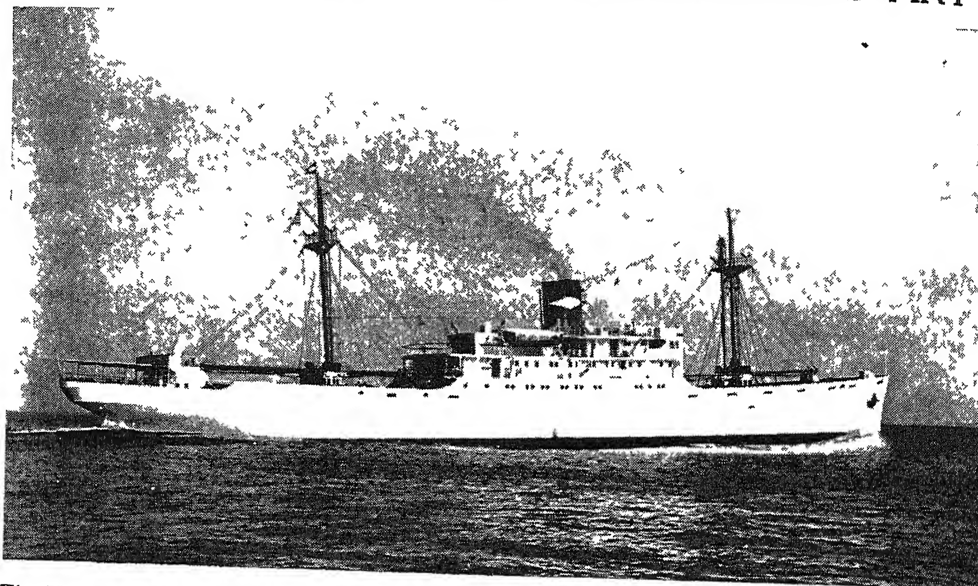
In November, 1923, another rival, and a formidable one, for the supremacy of the cave world was announced In the Guadalupe mountains of New Mexico, near Carlsbad and close to the Texas line, in the limestone of the Carboniferous age, is a cave said to equal, if not surpass, even the Mammoth Cave There are three entrances to this natural marvel, one descending to a depth of 750 feet One circular room, the King's Palace, 300 feet in diameter, has walls and ceiling hung with stalactites of every color of the rainbow Another room, the largest known of underground chambers, is 5000 feet long, 600 feet wide with a roof varying from 100 to 300 feet high

Carlsbad Caverns is not yet fully known though it has been explored and mapped by government geologists It was created a national park in 1930.



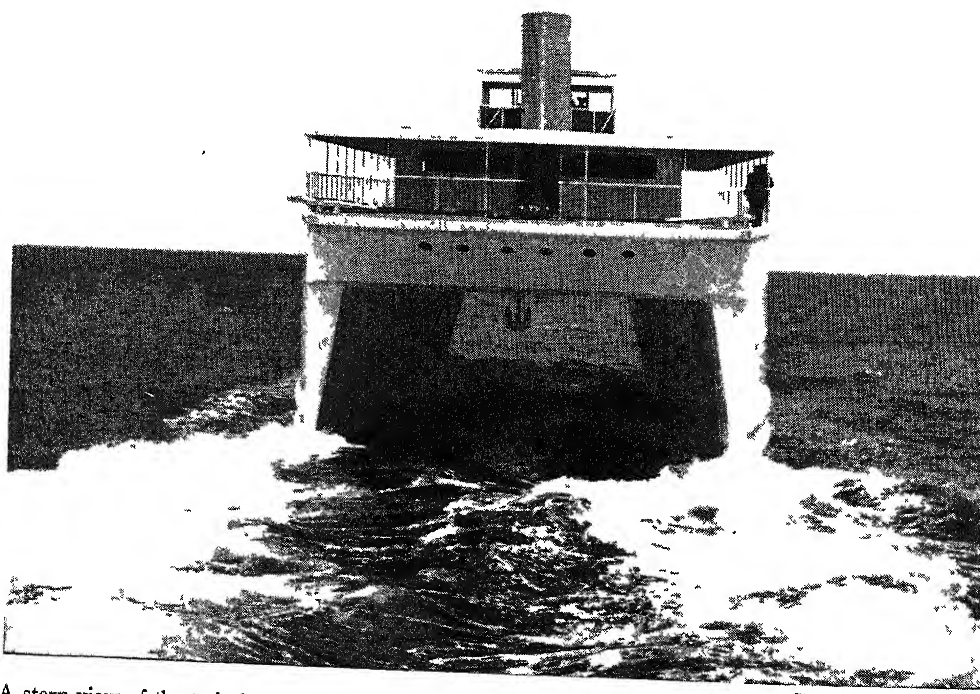
THE BLUE GROTTO, CAPRI

FINE SPECIMENS OF THE SHIPBUILDER'S ART



United Fruit Company

The Yaque, a good example of a modern freighter. With her smooth, streamlined silhouette and the gleaming white of her hull and superstructure, she is a far cry from the older type of cargo vessel



Steve Hannagan Associates

A stern view of the twin-hulled ship Venturi. The twin hulls prevent the craft from rolling and pitching. The air that rushes through the "tunnel" between the hulls provides added steadying support.

CONQUERING THE OCEAN

The Struggle for the Blue Ribbon of the Seas

by

DEXTER S. KIMBALL

PRIMITIVE man both by natural desire and necessity has everywhere made an effort to navigate the waters of his habitat. Under this pressure the crude raft or log was superseded by the dugout, so common to all such folk. In some cases these craft were noteworthy, as in those of the South Sea islanders, and those of the Alaskan tribes, which often held as many as sixty persons. The conception of a synthetic dugout, made by setting up a framework of ribs and covering it with planking, must be considered one of the greatest of inventions. The Indians of North America solved the problem of navigation by building the birch-bark canoe, an extraordinarily efficient little craft. So outstanding was its performance that it is still used, with little modification, not only by the descendants of these Indians but also by the white men who supplanted the Indians in most areas. Of course practically all our modern vessels, from the humble rowboat to the mighty 50,000-ton ocean liner, may be considered as latter-day forms of the first synthetic dugout.

The story of man's efforts to conquer the sea is, of course, a very long one. The old nations living around the Mediterranean were the first to navigate the ocean in a large way. The Phoenicians have come down to us as great navigators, venturing as far as England in their voyages. The Greeks, too, traveled far and wide in their ships; in the course of their voyaging they established colonies in many different areas—in France, in Italy, in Asia Minor. The ships that were built by these ancient nations, though of considerable size, were primitive in their equipment. If the wind was fair they spread a single great square sail and ran before it. If it was adverse or if there was none, they propelled their craft with oars, sometimes using three banks of them on each side so as to get sufficient propelling power. The great development of the sailing ship accompanied the rise of the English, French, Dutch, Spanish and Portuguese nations during the Middle Ages. The story of the exploration of the globe by these intrepid mariners is one of the most thrilling in the annals of the race, especially so when the smallness and slowness of their ships are considered.

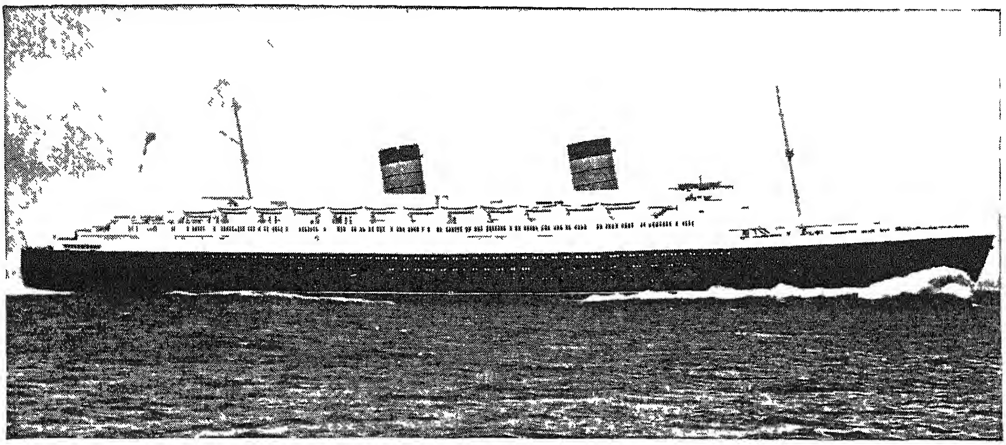
Sailing ships are classified roughly as "square-riggers" or "schooners" according to the manner in which their sails are rigged or "bent." On the square-rigger they are fastened to a horizontal wooden pole, or "yard," which in turn is attached to the mast by a connecting swivel. The normal position of this yard is at right angles to the length of the ship, but the swivel permits it to swing through a considerable angle, and thus be adjusted to the wind and the desired course of sailing. A large ship might have as many as six of these square sails on a single mast, decreasing in size the higher they are on the mast. This arrangement is, of course, a modification of the single great square sail of the ancients, and permits of greater flexibility and ease of handling with large sail area. In the schooner-rigged ship the sail is hoisted on the after side of the mast and is held in place by wooden spars, or "booms," fastened at one end to the mast and extending in an after direction. The normal position of the booms is parallel to the center line of the ship, but like the yards of the square sail they can swivel through a considerable angle so as to adjust the sail to wind and course, as a particular case might require.

This is also called a "fore and aft" rig. A square-rigged ship also carries several fore and aft triangular sails, known as jibs, between the bowsprit and the foremast, several similar small sails between the foremast and mainmast and between the mainmast and mizzen mast and known as staysails. The mizzen mast also carries a fore and aft sail of the same shape as that of a schooner. If the vessel carries square sails on all three masts in addition to these fore and aft sails it is designated as a "ship". If it carries only fore and aft sails on the mizzen mast it is called a "bark" or "barque." The schooner occasionally carries a square sail or two to be used in running before the wind. There are many and varied combinations of square and fore and aft sails used on comparatively small vessels, each bearing a specific designation—as brig, brigantine, barkentine, topsail schooner, etc.—but here we are concerned primarily with the larger craft known as ship, bark, and schooner. Normally a ship or bark has three masts, but quite a few of both have been built with four. Schooners usually have two or three, but many of this kind have been built with four, five, six and even seven.

As has been noted, the ships of the middle ages were small. Thus the three with which Columbus sailed on his great voyage of discovery were 100, 50, and 40 tons respectively. The largest of these would be considered very small today and the ships, so called, in which the Norsemen made long voyages were row boats compared to modern sailing craft. Yet they built some large ships in olden days. The Great Armada sent by Spain against England in 1588 consisted of 130, many of them ranging from about 350 to 1160 tons. The English fleet that defeated this formidable array consisted of much smaller, but faster vessels. Again, the *Royal George* built by England in 1740 was of 2041 tons. All of these ships, however, were slow and clumsy. Their bows were bluff and the hulls pot-like in form. They were square-rigged and while going before the wind probably made fairly good time. They were necessarily very inefficient in beating to windward, yet they must have been seaworthy for they went on long voyages in all kinds of weather.

It is generally conceded that the French were the first to modify these ancient models with a view to obtaining greater speed, and it is often contended that the American colonists got their first ideas from the French ships sent over to assist us during the Revolution. It is more likely that the need of the colonists for faster vessels was the real incentive. The colonists from the first took kindly to sea-borne commerce, and well before the Revolution they were making long commercial voyages. Without doubt, however their experiences during the Revolution and the War of 1812 increased their knowledge and desire for fast ships. At any rate, during the first quarter of the century there was steady progress in building them all along the Atlantic seaboard As early as 1829 vessels of 400 tons and less were crossing the Atlantic in 18 days and gradually the name "clipper" began to be applied to these long, lean racers that were steadily lowering the time between America and Europe and China. It is commonly stated that the *Ann McKim,* built in Baltimore, was the first "clipper ship." Probably, however, there were others as sharp and fine built about the same time. She was small, being only 143 feet in length. By 1850 sailing vessels of 1300 tons had been built, many of them very fast and many of them superbly beautiful.

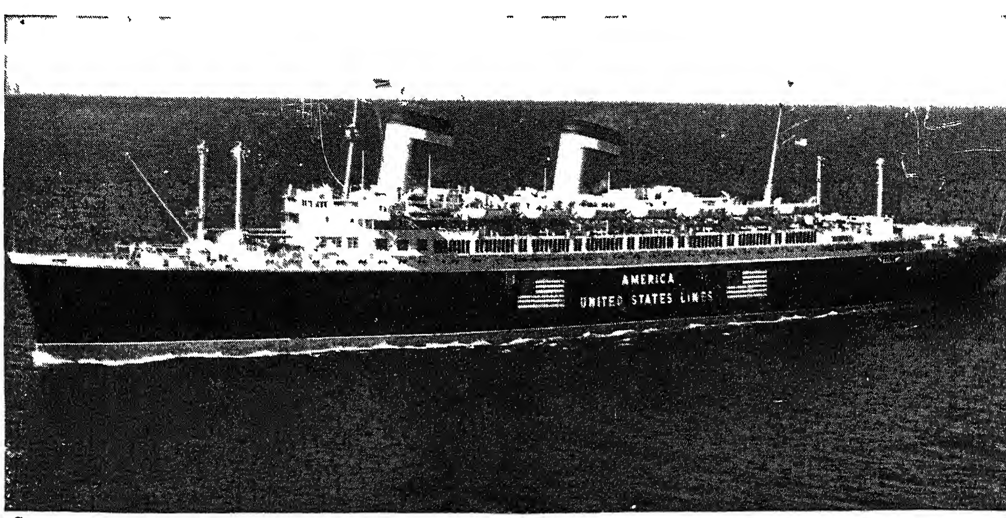
This progress paved the way for the golden age of the sailing ship, short and historic as it was to be. Up to this time steam-driven vessels had not been able to compete with the fast clippers, but this was soon to change. Before steam conquered sail, however, there was to be an outburst of shipbuilding and seamanship that will remain one of the greatest glories of the American people



Courtesy Cunard-White Star Line

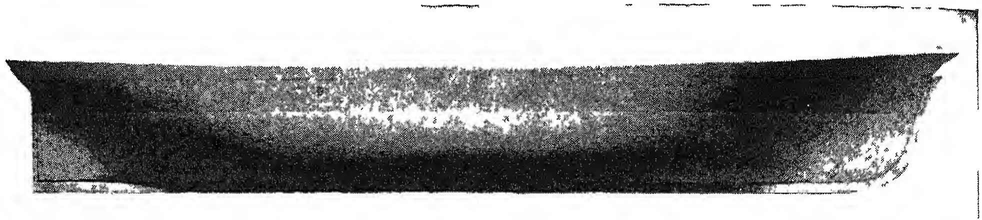
World's largest liner, the QUEEN ELIZABETH, 1030 feet long

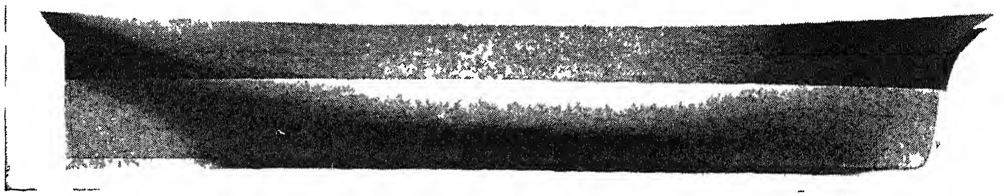
In 1849 the California gold fields were discovered, giving a tremendous impetus to shipbuilding as the only way freight could easily be shipped to that state was by water around Cape Horn. Under this incentive there were developed the most beautiful and fastest ships ever built. Most of them bore grandiose names such as *Challenge, Glory of the Seas, Invincible, Sovereign of the Seas,* etc. Outstanding among them was the *Flying Cloud,* very beautiful and fast, of 1800 tons, a large ship for those days. She sailed from New York to San Francisco, going around Cape Horn, in 89 days and 8 hours, a record that was never beaten by sailing vessels. The clipper *Andrew Jackson,* however, made the same passage in about the same time, giving rise to a debate between admirers of the two which is not important as both voyages were very fast and have never been equaled. The *Flying Cloud* continued from San Francisco to Hong Kong making the run in 37 days or 127 sailing days from New York, again making a record that was never equaled. She made many other very fast voyages. Another very fast ship, the *Red Jacket,* named after a famous Indian chief, built in 1854, ran from New York to Liver-



Courtesy United States Lines

American Liner, AMERICA (renamed WEST POINT), 772 feet in length.





From *Greyhounds of the Sea*, by Carl C Cutler, courtesy of G P Putnam's Sons

UPPER: The extreme clipper *Lightning* Her long hollow bow is probably the sharpest ever put on an American ship, but her flat floor and relatively full run gave her great stability and power

LOWER Builder's model of the *Red Jacket* A very sharp, beautiful three decker with flat floor and rounding sides and bilges. One of the speediest and most efficient of the clippers

pool in 13 days 1 hour and 25 minutes. The fastest authenticated record for fast sailing is that of the clipper *Lightning* which in a trip from New York to Liverpool in 1854 sailed 436 nautical miles in 24 hours, which was 23 miles better than the best similar record of the *Red Jacket,* and is probably the best record ever made by a sailing ship though there are other claims, not apparently so well authenticated, in excess of this. It was many years before a steamship equaled the record of this swift vessel. The accompanying illustration shows the builder's half-model of both these ships and their beautiful and fast lines are obvious. It should be noted that a nautical mile is 6080.2 feet whereas a land mile is only 5280 feet; also that the term "knot" so much used in maritime language, is a rate of motion and not a measured distance. By definition a knot means one nautical mile per hour so that when a vessel is sailing at the rate of 10 nautical miles per hour she is said to be "making 10 knots." The largest full clipper ship was the *Great Republic,* of 4555 tons, built in 1853 by Donald McKay who also designed and built the *Flying Cloud* and the *Lightning*. She was rigged as a four-masted bark but was partially burned at the dock before her maiden voyage and when rerigged her masts and spars were greatly reduced in length, which was most unfortunate since as first sparred she might have broken all sailing records.

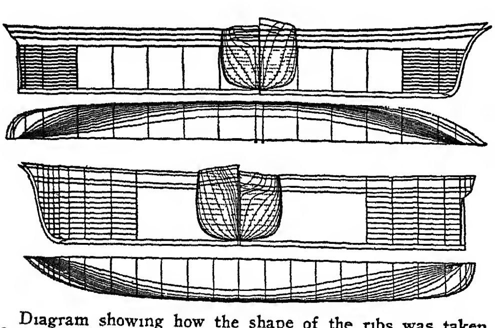
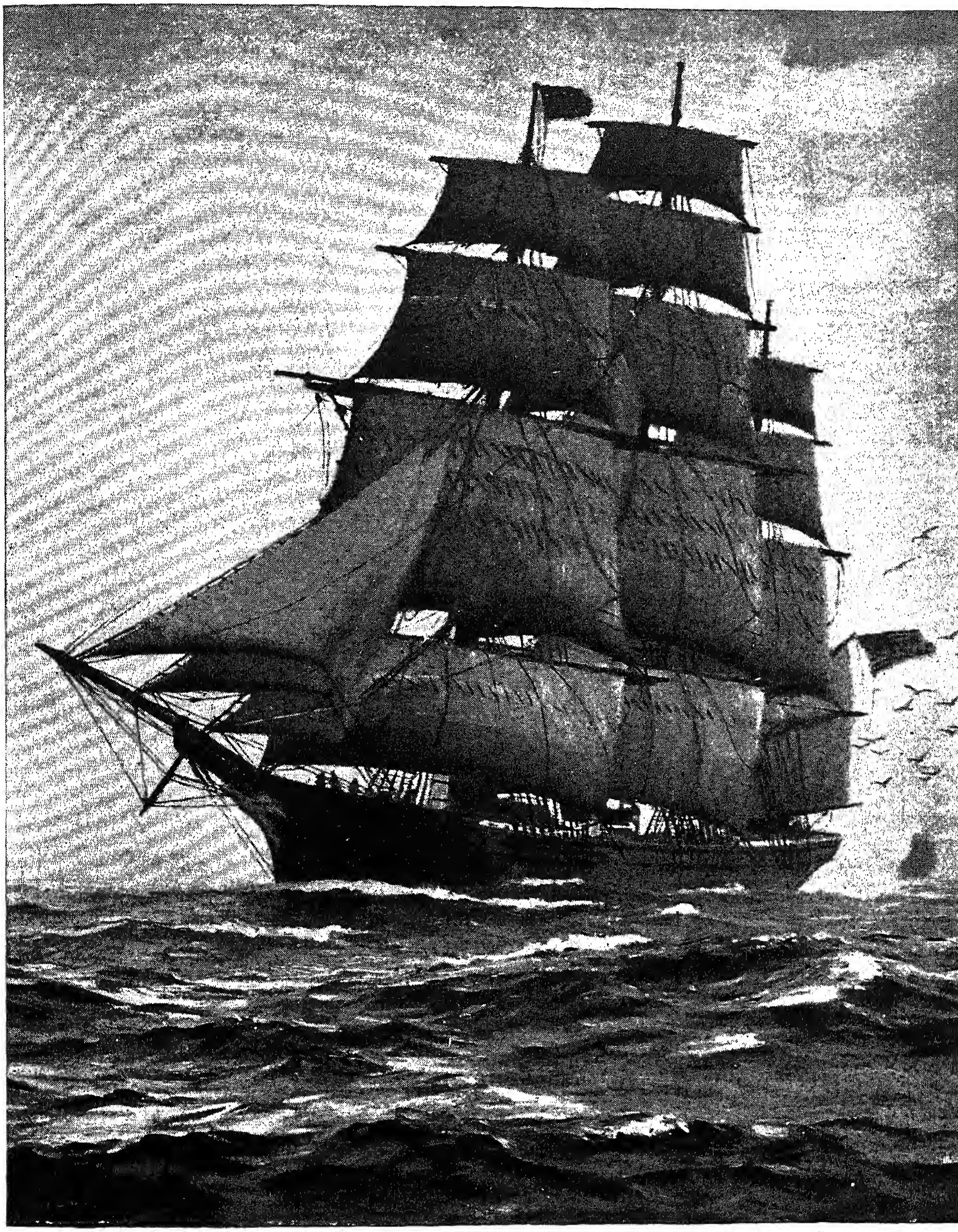


Diagram showing how the shape of the ribs was taken from the model.
From Cutler's *Greyhounds of the Sea*, by permission of G P. Putnam's Sons

These clipper ships were all built of wood. The shape and form of the great ribs were laid out by enlarging the several cross sections of the wooden model. These were fastened to the wooden keel and held to shape by cross beams. In small ships there would be only one set of such crossbeams carrying the main deck, but in very large ones there were often three such sets, making a "three decker." The "planking," or outside covering, was bent around the ribs and firmly fastened to them. In many of

THE GOLDEN AGE OF THE CLIPPER SHIP



Courtesy Columbian Rope Co.

The clipper ship DREADNOUGHT, from a painting by Charles Robert Patterson.

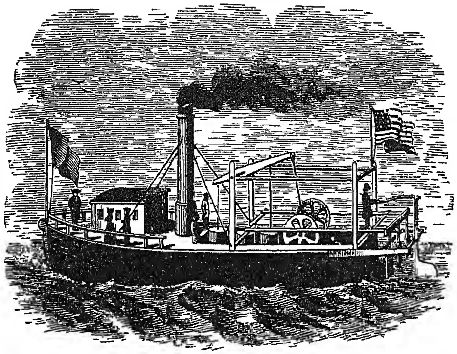
them the fastenings were wooden pins or "treenails" usually made of hardwood, such as locust. Of course some iron fastenings were also employed and in many English ships the timber was often oak and the fastenings of copper. Such vessels were very long-lived.

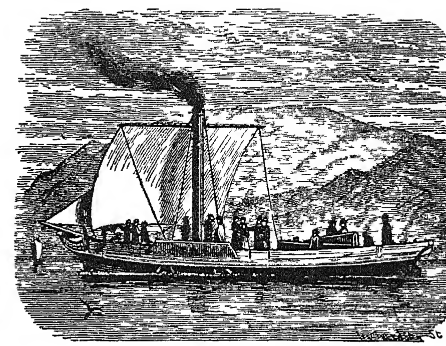
The golden age of the clipper ship was very short. In a brief ten years it was over. A railroad spanned the continent and steamships were rapidly assuming command of the sea. Yet the building of sailing ships continued until near the close of the century and many large and fast ones were constructed. These ships of a later day were greatly modified forms of the clipper, not so fast but better cargo carriers. Modifications in construction also appeared in the form of "composite" ships. These vessels had iron frames with wood planking on sides and deck and finally hulls made completely of iron appeared. Yet the last attempt of the backers of sailing craft in America to stem the opposition of steam were several large wooden ships launched around 1890. Of these the *Shenandoah* was the largest, being 300 feet long and of 3258 net tonnage. Her lower or main yards were 92 feet long and she spread 11,000 yards of canvas. Her right and left "bower" anchors weighed 6800 and 6400 pounds respectively. But this was the beginning of the end. By the close of the century steam had triumphed and the great sailing ships had begun to disappear from the seas. Of course there are still many small coasting vessels, mostly schooners, that use sails and a very few of the old large square riggers still eke out a precarious existence. But every great seaport shelters many of the old "windjammers" dismasted and forlorn. When they go to sea they no longer spread their immense white pinions, but follow meekly in single file behind a powerful and unromantic ocean-going tow boat, bearing coal or some other ordinary commodity. The glory of the sea has departed, for a three-masted full-rigged American clipper ship under full sail was the most glorious, the most romantic and the most thrilling spectacle that the eye of man has ever rested upon. Without doubt, the performances of these clippers were due in no small measure to the skill, courage, and driving power of their captains. The history of the period shows them to have been a very remarkable group of seamen.

While the clipper ship was developed in the United States, England was quick to follow the example and sent out many fast vessels. One of the most notable of these is the *Cutty Sark* which is still afloat and preserved in England. During the latter part of the last century numerous fine iron ships were built in England and Scotland. Many of these were large four masted barks, often characterized by beautiful carved figureheads and a row of imitation gun ports painted along the sides. Thirty years ago many of these craft were to be seen in San Francisco Bay loading grain for England and a few of them are still to be found in Pacific Coast ports, while a few others owned in Finland still carry cargoes from Australia to Europe. But they are the last of their kind. Ichabod! the glory has indeed departed.

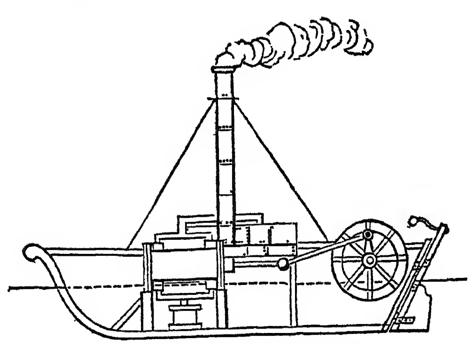
Development of steam navigation

The steam engine was invented near the end of the 18th century and was quickly adapted to pumping water from mines and for use on railroads. By the year 1850, the clipper ship era, the locomotive and the stationary engine were well developed and firmly established. Less progress, however, had been made in steam navigation. The *Savannah,* the first vessel driven by steam to cross the Atlantic, sailed from Savannah, Georgia, to England and thence to Russia in 1819. But, comparatively speaking, marine propulsion had lagged or rather the competition of the sailing vessel was greater than anything offered to land problems of power or transportation. An extended account of the trials

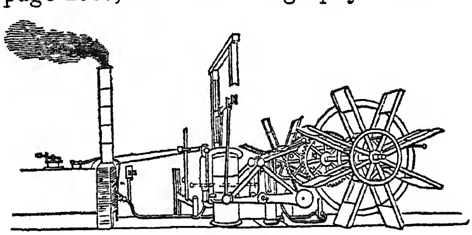

John Fitch's steamboat of 1788


The Comet, 1812

and tribulations of the early inventors of steamships would be far too long to be included here, but it may be instructive to glance at them. The accompanying illustration shows the effort of John Fitch in 1788 in which he propelled his craft by paddles operated by a very primitive steam engine. He also experimented with a primitive form of screw at the stern of another boat in 1796. These are typical of the crude beginnings of steam navigation. In 1801 the *Charlotte Dundas,* said to be the first practical steamboat, was built by William Symmington in Scotland. As can be seen it was the first "sidewheeler" to operate successfully. The second successful attempt was that made by Henry Bell who in 1812 constructed the *Comet* on the Clyde. This boat was 40 feet long and was driven by two paddle wheels on each side. This was the beginning of steam navigation in British waters and in 1840 there were 1325 steam vessels operating in England and Scotland.


The Charlotte Dundas, 1801

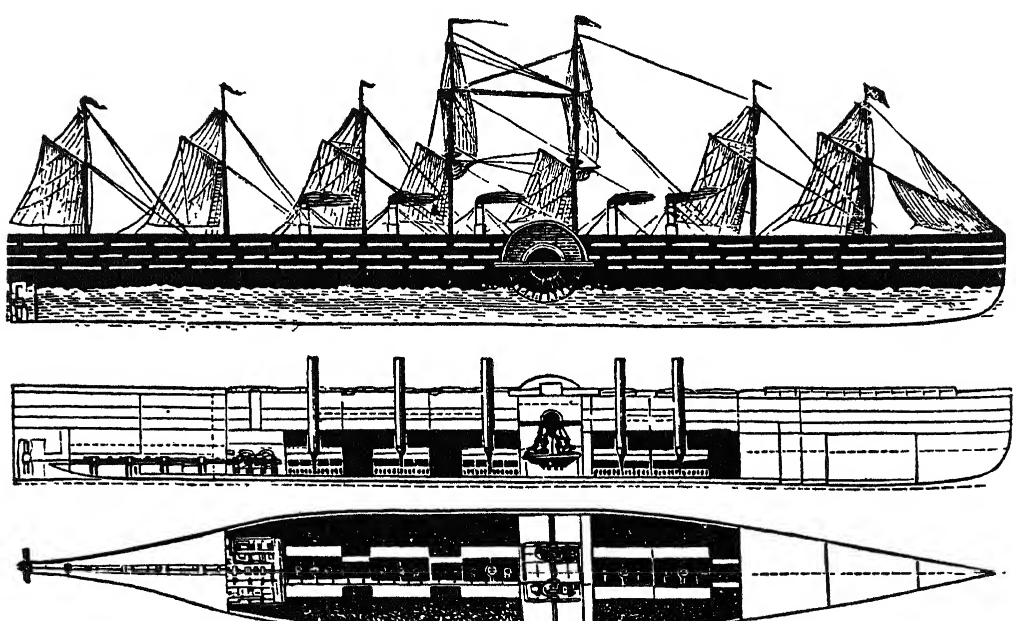
Among those who saw the *Charlotte Dundas* and also Bell's first imperfect experiments was an American, Robert Fulton, who also had constructed a small steamboat on the Seine in 1803 He returned to the United States in 1806 but before doing so he ordered an engine from Boulton and Watt in England which was built to his plans. This engine, a picture of which is shown, had a cylinder 2 feet in diameter and of 4 feet stroke He immediately proceeded to build the *Clermont,* the first commercially successful steamboat. A picture of her will be found in Volume VII, page 2308, in a brief biography of Fulton.


Engine of the Clermont, 1808

She was 133 feet long and made about 5 miles per hour. The accounts of her first passage up the Hudson to Albany are quite ludicrous. The inhabitants not having even heard of her construction were badly frightened and she was described as "a monster moving on the waters defying wind and tide and breathing flames and smoke." The *Clermont* furnished the model which with many improvements, characterizes all American steamboat traffic in inland waters. The side wheels are still much

used, since they are well suited to shallow waters and vessels so driven are smoother in motion than screw-driven craft. The largest steamer in inland waters the *C & B,* an abbreviation of Cleveland and Buffalo, is driven by side wheels. We are not here concerned, however, with inland traffic.

The first steamship to cross the Atlantic was the *Savannâh,* already referred to as making the trip in 1819. This vessel was really a full rigged ship with an auxiliary engine of 40 inches diameter and 6 feet stroke, driving side wheels, considerable dependence being placed upon the sails. Indeed it was many years before sails were discarded and complete reliance placed upon the engines. The voyages of the *Savannah* were commercially unsuccessful, and the engine was removed. At this time the opinion was widely held that the transatlantic passage was quite impracticable for steamers just as we today doubt the success of air craft on such long voyages. However, in 1825 two British ships, the *Sirius,* 700 tons and 250 horsepower and the *Great Western,* 1340 tons and 450 horsepower, both crossed the Atlantic and both arrived in New York the same day. The former made the passage in 19 days and the latter in 15. The return voyages were made in 18 and 15 days respectively, both still longer than best clipper ship records. This, however, was the real beginning of the conquest of the sea and from that time on Atlantic steamship service has gone on without interruption. The famous Cunard Line was established in 1840 and their first ship, the *Britannia,* was of about 1200 tons and made only eight knots. Progress was steady and sure, however, and by 1850, the clipper ship era, paddle wheel steamers were being built that marked the high point of this class of craft on ocean waters. Iron hulls began also to appear. The *Atlantic,* built in 1851, may be taken as a good example of the best ocean going ships of the time. She was 276 feet long and of 2860 tons. Her bow was sharp and the lines of her hull were fine, reflecting the progress made at that time in sailing ships. She was beautifully fitted up and was among the first of transatlantic ships to provide the luxurious service that has so long marked



The GREAT EASTERN, 1858

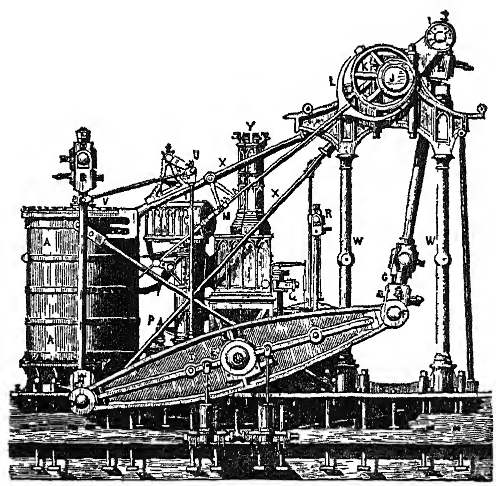
that trade. Yet the best crossing of the Atlantic at this time was about 10 days.

In 1854 a notable ship was started in England and completed in 1858. This was the famous *Great Eastern,* 680 feet long, 83 feet wide and of 18,915 gross tonnage. She was driven by both paddle wheels and a propeller. The former were operated by four engines each 74 inches in diameter and 14 feet stroke. The propeller was also driven by four engines, 84 inches in diameter and 4 feet stroke. Collectively these engines furnished 10,000 horsepower. The paddle wheels were 56 feet and the screw 24 feet in diameter. Her estimated speed was 16½ miles per hour. The vessel was also equipped with seven masts all rigged with sails. This large ship was in advance of her time and, though used in laying Atlantic cables, was not a commercial success. However, it was not until 1899 that a steamship of greater size or length was launched.

Three very marked changes were now to take place in steamship building. The first was the wide adoption of iron in place of wood for hull construction. Iron vessels had been built as early as 1818, but for many years there was a decided prejudice against iron, based primarily upon the idea that an iron ship was not as buoyant as one made of wood and possibly the cost was greater. Large iron vessels of 3400 tons had been built as early as 1840. The Cunard Company built their last wooden ship in 1852 and their last paddle wheel steamship in 1862. Steel replaced iron in shipbuilding about 1880. Quite a few steamships of the composite type were also built during the latter part of the century.

The second and more significant change was in the propelling machinery. The accompanying illustration shows a typical "side lever" engine in most common use in the paddle wheel ships in the middle of the century. The cylinder A is of the "inverted" type the crosshead rising from it and connected by links B to a rocker arm E. This in turn drove the crank I through a connecting rod G. The paddle wheels were attached to the ends of the crank shaft J. Such engines were necessarily of the slow speed type, but well fitted to drive paddle wheels the rotative speed of which was necessarily low. Another form of this engine is the "walking beam" type, common on river steamers.

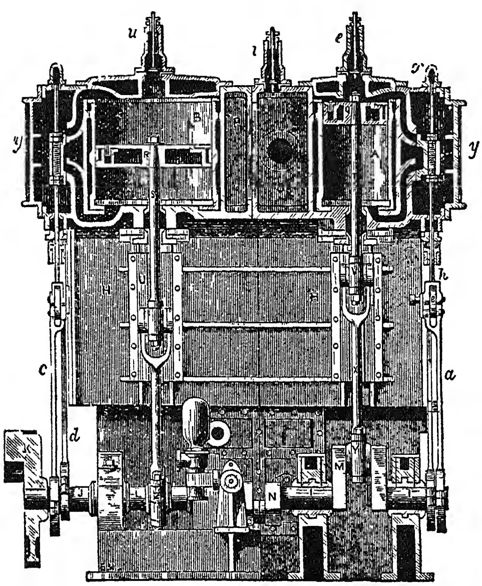
Furthermore, steam is used efficiently when it is used *expansively* and the long stroke cylinder employed at this time permitted this to be done fairly well in a single cylinder. Steam pressures were very low and by using a condenser the



Side lever engine of the ATLANTIC, 1851

steam could be expanded and exhausted from the cylinder below atmospheric pressure. The advantages of the screw propeller had long been recognized and debated. In fact, one very large steamship, the *Great Britain* of 3610 tons, making her first voyage in 1845, was driven by a propeller. But even in spite of this, large paddle wheel vessels were built for a long time thereafter. The last side wheeler launched by the Cunard Line was the *Scotia,* 379 feet long and of 3871 tons. The two cylinders of the engines were 100 and 144 inches in diameter respectively. The paddle wheels were 40 feet in diameter and the speed 14.4 knots. Thus these engines were very large and slow moving

The screw propeller from its nature and the fact that it is submerged is necessarily smaller and must rotate faster than the ponderous paddle wheel described above, and this necessitated a different kind of engine unless the propeller shaft was geared to the engine shaft so as to increase its relative rotative speed. This problem was solved by the introduction of the "compound engine", so-called, an early form of which is shown in the accompanying illustration. It consists, as will be seen, of two steam cylinders connected to cranks spaced at right angles to each other. Steam is ad-



Sectional view of the compound engine that came into use about 1860

mitted to the high pressure cylinder by the valve y and is cut off at a little more than half stroke. It is then expanded the remainder of the stroke and exhausted to the low pressure valve y^1 which admits it to the low pressure cylinder B cutting it off again at a little more than half stroke and expanding it the remainder of the stroke. From the low pressure cylinder the steam is exhausted to the condenser. Such an engine, having a shorter stroke, rotates faster than the long stroke engine and can, therefore, be designed to give the correct rotative speed to the screw. The first compound engine appears to have been installed in the steamship *Brandon* in 1854 by John Elder in England and this marked the passing of the paddle wheel steamship for ocean traffic.

The third important improvement that was applied to steamships during the 1850's was the surface condenser. This was not a new invention, but had long been discussed. Up to this time the steam from the engine was condensed by spraying it with a jet of salt water, hence the name "jet condenser". This method was copied from land practice. This hot and partially salt water was then pumped back into the boiler or as much of it as was needed to supply steam. The remaining excess went overboard, carrying considerable heat with it. In addition, the salt water encrusted the inside of the boiler, limiting the temperature and pressure that could be carried therein. In the surface condenser the salt condensing water is passed through a large number of small brass tubes arranged in a casing so that the exhaust steam may be passed over the outside of these tubes, thus condensing it without admixture of salt water. This condensate is returned to the boiler, the small amount of waste due to leakage being made up from a fresh water tank.

When Elder introduced the compound engine steam pressures were about 60 pounds to the square inch. With the improvements described above and in the materials and methods used in making boilers steam pressures began to rise until, by the end of the century, 200 pounds to the square inch was not uncommon and 250 and even 300 pounds were in use. The compound engine was succeeded by the triple expansion and that again by the quadruple expansion as ships became larger and larger and steam pressures higher. Most important, also, the fuel consumption fell from 10 pounds of coal per horsepower per hour with 5 or 6 pounds of steam, to $1\frac{1}{4}$ pounds or less with 200 pounds of steam to the square inch.

With improvements in the form of hulls and the possibility of installing more power in the ship speeds rose rapidly and the race for the "blue ribbon of the seas" was on in earnest. During the period 1890-1900 larger and faster ships appeared, each new vessel endeavoring to reduce the time of crossing. In 1893 the Cunard Line commissioned the *Campania* and the *Lucania*. They were 620 feet long, 12,950 tons and 28,000 horsepower. They were almost as long therefore as the *Great Eastern,* and of course much faster. These ships crossed the Atlantic in less than six days. In 1900 the Hamburg American Company put into service their famous *Deutschland* and a little later the Nord-Deutscher Lloyd Line commissioned the *Kaiser Wilhelm II.* This last was 684 feet long, or somewhat longer than the *Great Eastern,* had a gross tonnage of 19,361 and made 23½ knots—a record for the time.

Thus in a century the conquest of the sea that had intrigued man from the beginning was complete. The passage of a sailing ship was and is always fraught with danger, however glorious it may be, and there is still danger on the sea for small or medium sized steamships. But the passenger on the great liner is safer by far than he is in the streets of a crowded city and the passenger service between New York and England or the Continent is little more than a glorified ferry. Since 1900 there has been a great advance in both size and speed of ocean liners, but before discussing these modern monsters it may be edifying to note some of the advances in the powering of ships that have helped to make them possible. These in general are four:

(1) Improved boilers permitting higher steam pressures;
(2) The development of the Diesel engine;
(3) The development of the steam turbine;
(4) The development of the electric drive.

As concerns the first, the rise in steam pressures on ships is, of course, the natural result of the great improvement which has taken place in boilers in general. Another determining factor is the boiler space available. This dictates somewhat the form of boiler that may be used, the very tall, highly efficient type now in use in land installations being out of the question. Many forms were tried during the period of development, but as the need of higher pressures grew the so-called "Scotch" boiler assumed greatest prominence. This consists primarily of a cylindrical shell with flat ends. The fire box and tubes are enclosed in the shell and surrounded on their exterior surfaces by the steam and water. They are, therefore, of the "fire tube" type. All flat surfaces must be heavily stayed, which in itself tends to limit the steam pressure. In boilers of this kind of 12 or 13 feet in diameter the great outer shells were sometimes as much as 1¼ inches in thickness and the problem of making the riveted joints in them was troublesome. They were long popular because of their simplicity and their capacity for hard service. As an illustration, the *City of Pekin,* which was operated by the Pacific Mail Company during the last decade of the last century, was equipped with ten boilers, each 13 feet in diameter and 13½ feet long. The outer shell was 13/16 inches thick though the pressure was only 60 pounds per square inch. Each boiler had three furnaces and 204 tubes of 3¼ inches outside diameter. The "water tube" type of boiler, it will be remembered, consists of combinations of small drums and small tubes that contain the water and steam, the heat being applied to the exterior. They superseded the fire tube type for naval service long before they became popular in the merchant marine. All modern steamships that use high pressure steam are now equipped with water tube boilers of which there are many forms. They are much safer against explosion than the fire tube

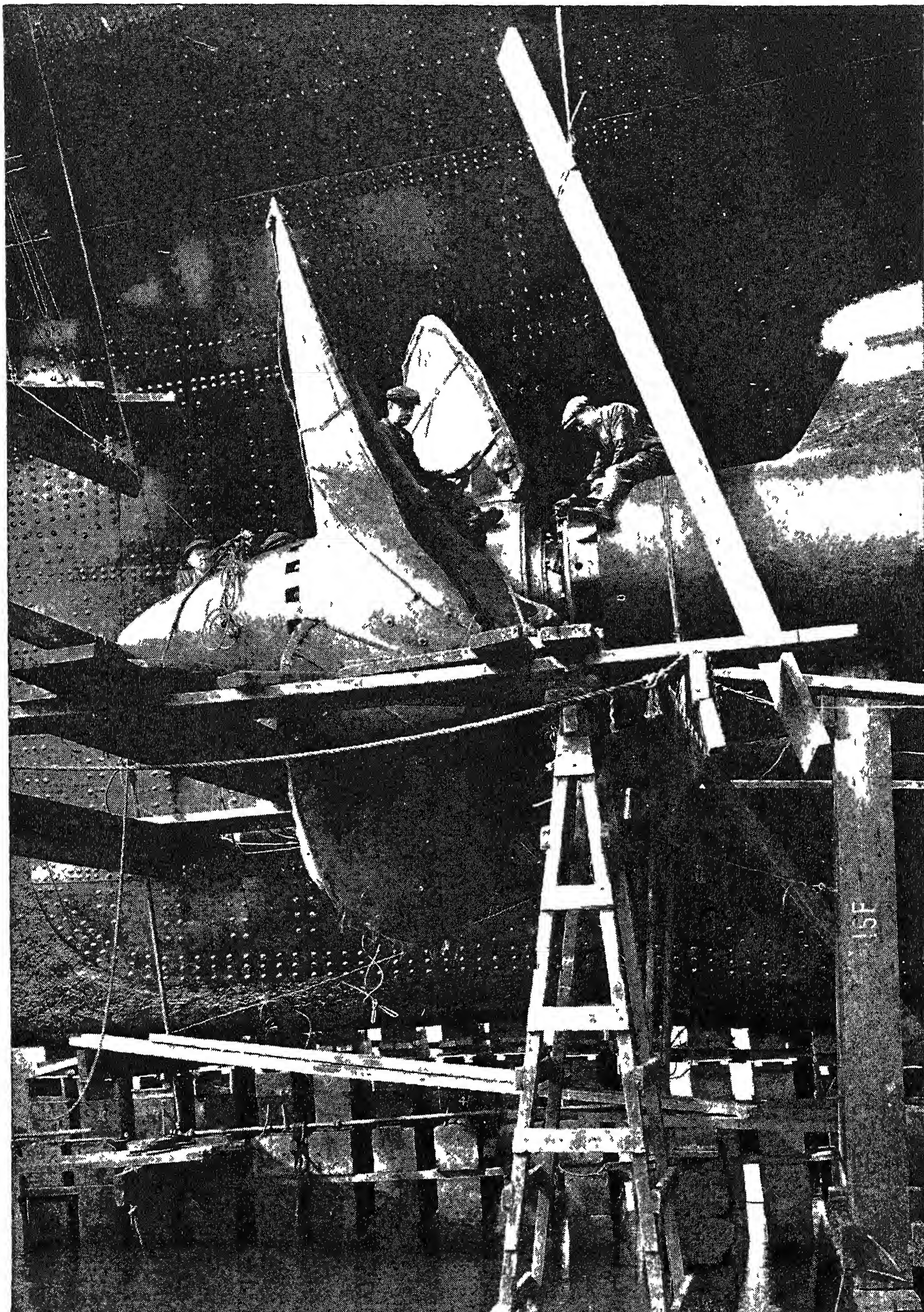
type, partly because of the smaller elements involved and partly due to the smaller amount of energy bottled up, the fire tube boiler holding much more water than the water tube boiler. In addition to these structural changes the use of oil instead of coal has made steady progress. Today almost all large modern ships that are steam driven use oil as fuel. Not only is oil much more convenient and cleanly, but it is easier to keep steam up to full pressure with its use, and, in addition, the fuel storage space is much reduced as compared with coal. Getting the coal from the coal bunkers and firing it to the boilers in a large ship requires a big force of men and is laborious and dirty work.

In recent years there has been a considerable increase in the size of Diesel engines and in their application to use as a prime mover in marine work. Mechanical difficulties have been surmounted and larger ships are being equipped with this form of engine. It has been found to be particularly useful in cargo carrying vessels. The great advantage of the Diesel engine as compared to the steam engine is the saving of space due to the absence of boilers and the reduced fuel storage, thus adding to the cargo carrying space. The Diesel engine is also very efficiently thermodynamically and requires fewer attendants than a steam installation. The Diesel engine itself is heavier per horsepower than the steam engine and is not so flexible in operation. The upkeep is relatively high. Its rotative speed, however, is well adapted for direct attachment to the propeller shaft and in its present highly developed form it has proven its reliability, which is a matter of greatest importance in shipwork.

The turbine is a revival of the earliest form of steam engine, namely, the steam-jet rotary engine of Hero who lived in Alexandria 2000 years or more ago. The modern turbine was developed by Sir Charles A. Parsons. A description of both the ancient and modern will be found in Volume II, page 387. As compared to the reciprocating engine the efficiency is high, but like the Diesel it is not flexible in operation. For instance, an extra reversing turbine must be provided for putting the ship astern. This reversing turbine is much smaller than the main turbine. Of course, in very large ships this is not such an important matter as they are always assisted to and from their docks by tow boats. All turbines necessarily run at high rotative speeds and in the case of marine propulsion these rotative speeds are usually much higher than efficient propeller speeds. To overcome this difficulty the turbine is geared to the propeller shaft by speed reducing gears. It is interesting to note that this method is not new. The *Great Britain*, a pioneer experiment with propeller propulsion, built in 1845, was driven by a four cylinder engine each cylinder being 80 inches in diameter and 72 inches stroke. This great engine necessarily of slow rotative speed, drove the propeller shaft through a chain and sprocket device thus speeding up the shaft. It must have been a huge and very noisy contrivance. The turbine gear reduction, at first a troublesome problem, is now highly developed and reliable. The turbine, like the reciprocating engine, may be built in several stages in order to secure proper expansion of the steam and, like the reciprocating engine, there are so-called simple, compound, triple, or quadruple expansion turbines according to the number of units used to complete the expansion desired. The turbine, like the paddle wheel, has an advantage over the vertical reciprocating engine in being free from violent vibrations so undesirable in marine propulsion.

In the electric drive, so-called, an electric generator is driven directly by the prime mover whether this be a reciprocating steam engine, a Diesel engine, or a steam turbine. An electric motor is fastened directly to the propeller shaft. In the electric circuit connecting the generator with the motor

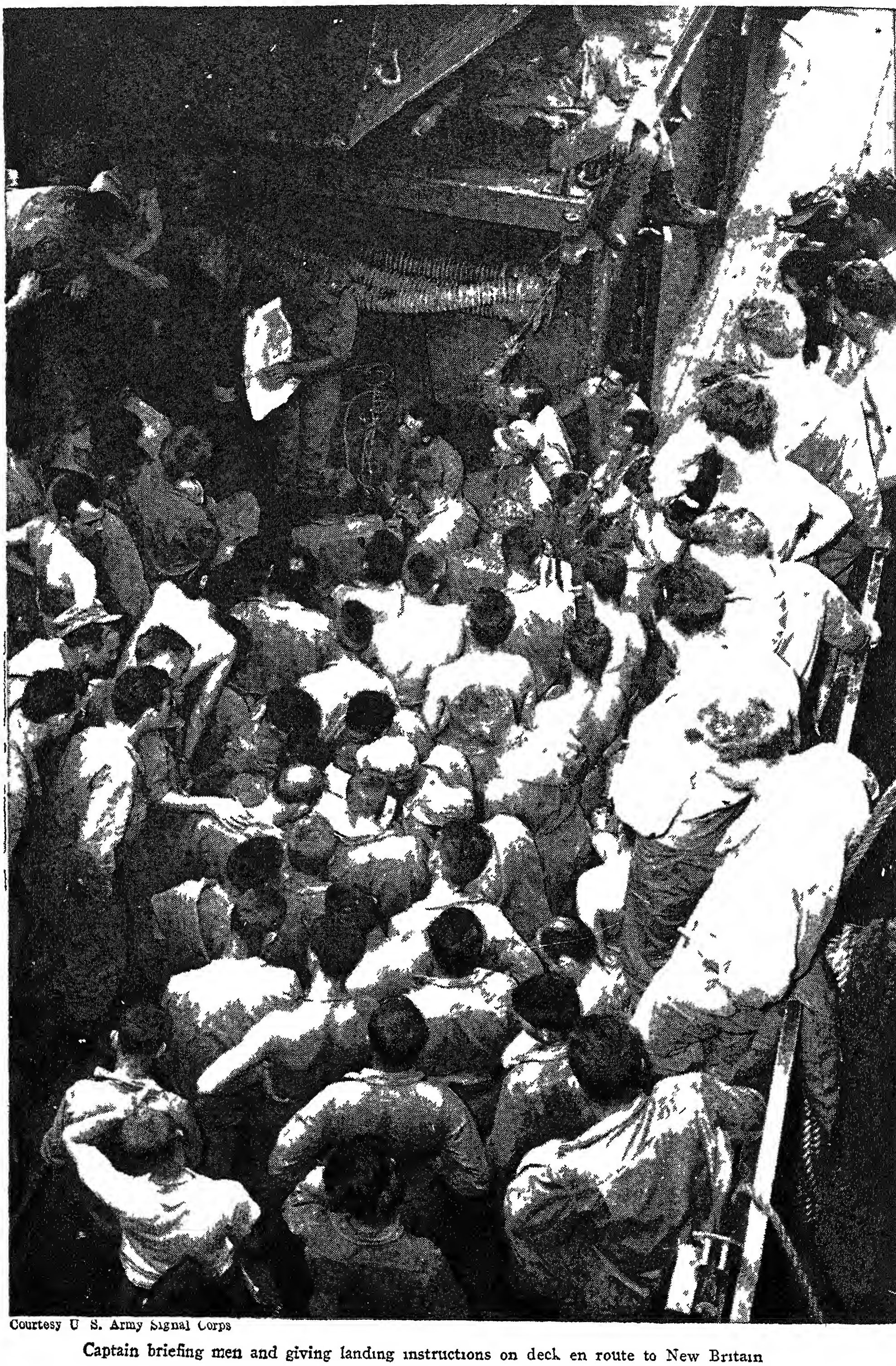
WHERE THE ENORMOUS POWER IS APPLIED



Courtesy Cunard-White Star Line

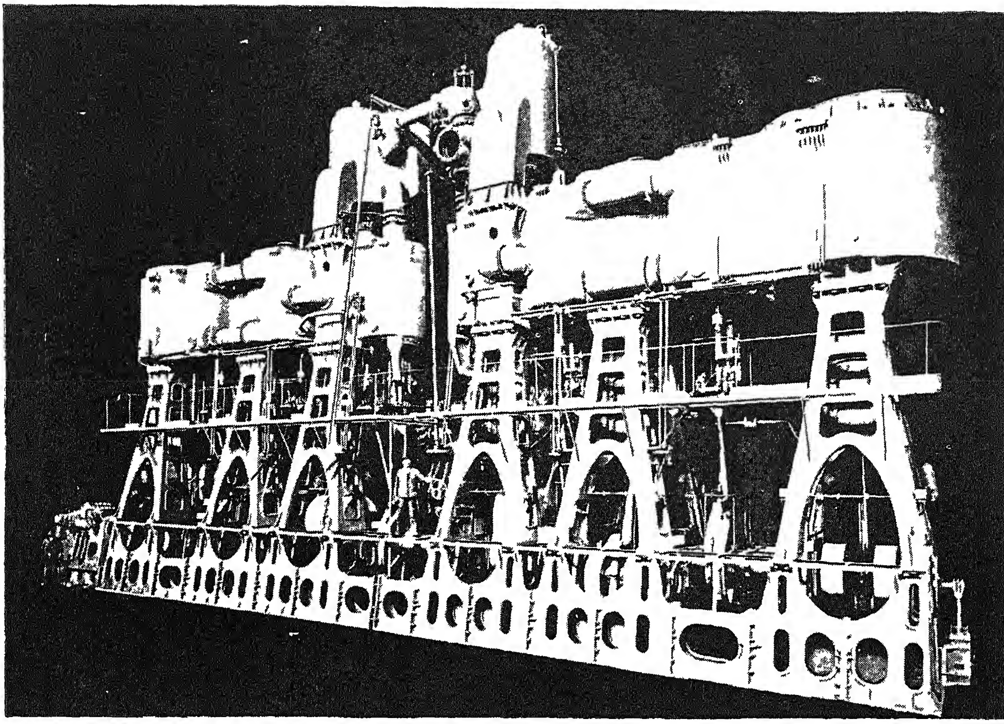
One of the four propellers of the QUEEN MARY, each of which weighs thirty-five tons and measures twenty feet in diameter. The ship carries two on each side.

TROOPSHIP IN WORLD WAR II



Courtesy U S. Army Signal Corps

Captain briefing men and giving landing instructions on deck en route to New Britain



Two of the four huge vertical, quadruple expansion engines each of 10 000 horsepower attached in pairs to each of the two propeller shafts of the KAISER WILHELM II

there is placed a switchboard through which the motor is controlled to run at any desired speed ahead or astern. The prime mover runs at a fixed speed and from the nature of such machines it will deliver any amount of energy from zero to full load as desired while running at or near its normal rotative speed. This makes a very flexible control mechanism and in small vessels, such as ferry boats, this control can be operated from the pilot house giving the pilot a great advantage in point of quickness in controlling his craft. Many such ferry boats and other similarly controlled small vessels are now in operation The system is also in extended use in locomotives driven primarily by the ordinary gasoline engine or by a Diesel engine. Quite a number of large ships have been equipped with this form of drive including the U. S. battleship *California*. The greatest disadvantage of the system is its costliness in large units. Both direct and alternating current have been applied in installations of this kind.

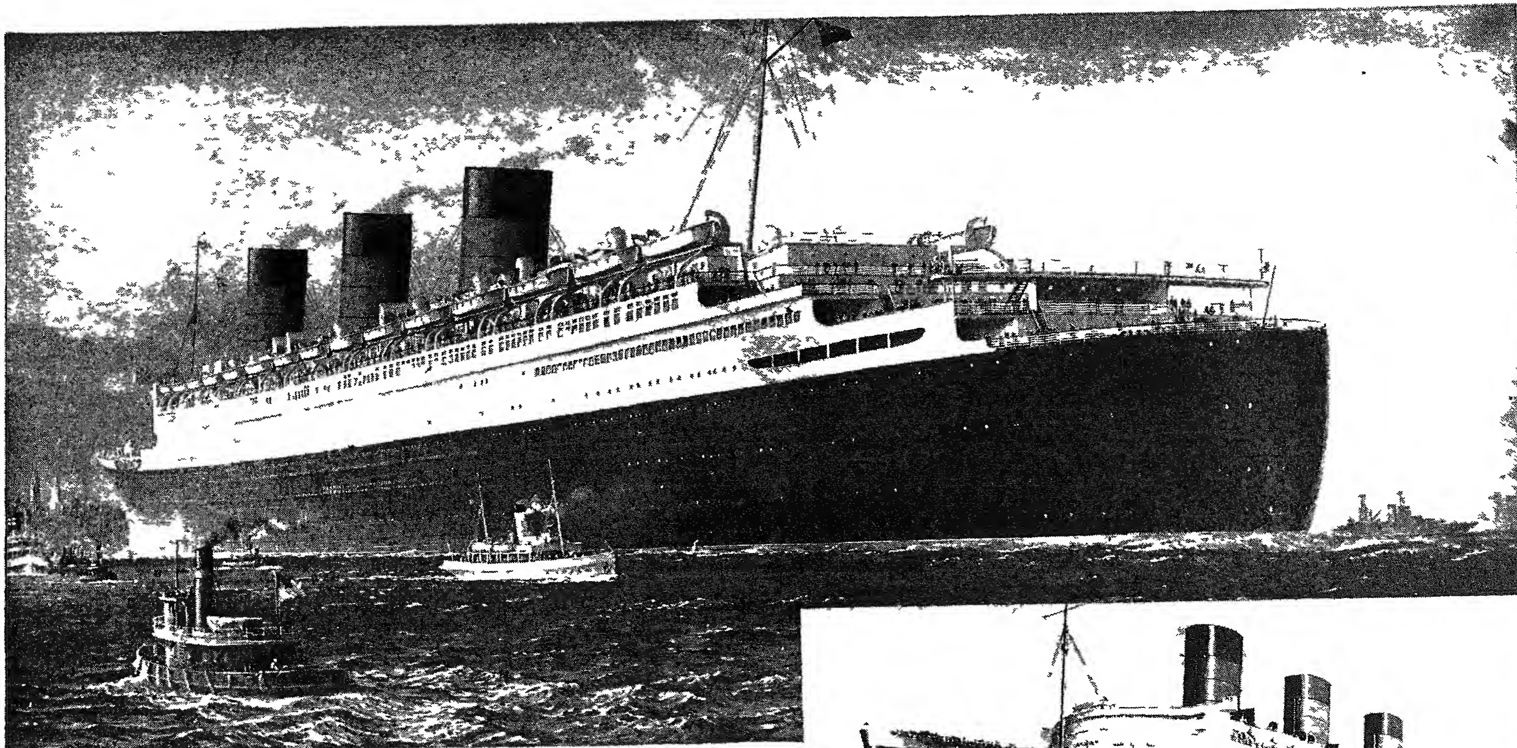
Summing up then the ship designer has a choice of the following methods of propulsion:

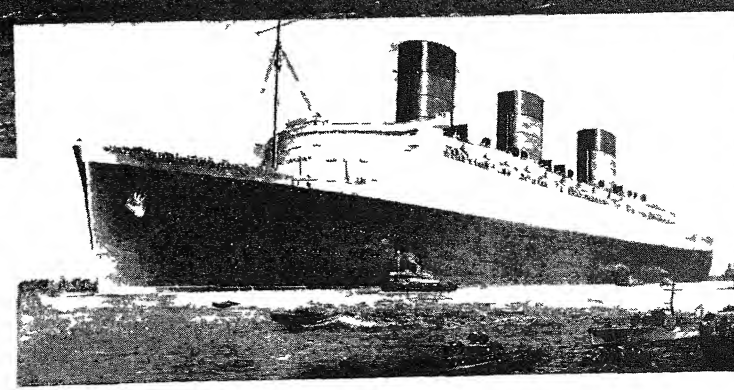
(1) Reciprocating steam engine direct-connected to the propeller shaft.
(2) Diesel engine direct-connected to the propeller shaft.
(3) Steam turbine direct-connected to propeller shaft through reduction gearing
(4) Electric drive using either reciprocating steam engine, Diesel engine or steam turbine.

Summary

The foregoing account has shown the progress made in transatlantic navigation in the period extending from 1830 to 1900. From 1840 to about 1852 all steamships were built of wood and driven by paddle wheels. Iron ships began to be common about 1852, but paddle wheels con-

TWO VIEWS OF A CUNARD SUPERLINER





Above: The Queen Mary, stern on, entering New York harbor. Right: The Queen Mary, bow on. These are architect's drawings. The length of this superliner is 1,020 feet; its tonnage, 81,273 (gross tons); its speed, over 30 knots

tinued to be used as late as 1862. About that date single screw steamers came into use and held the field well up to 1890. Steamships equipped with masts carrying sails as an emergency measure were built till late in the last century. Steel began to be used for hulls about 1880. The twin screw steamer dates from before 1900 and since that time twin screws and quadruple screws have been used for all large steamships. Three screws, that is, one in the center and one on each side, have not proven to be very advantageous. The large vertical reciprocating engine began to be superseded by the turbine shortly after 1900. The reasons for this are several. The accompanying illustration of one of the two main engines of the *Kaiser Wilhelm II,* which could develop 20,000 horsepower, shows it to be a ponderous affair. Moreover the vibration inherent with the vertical reciprocating motion of the great pistons, piston rods and connecting rods is trying to both ship and passenger. The turbine is free from all such vibration and for that reason alone is preferable in these great units. So far, it is the most favored for propelling very large ships. The Diesel engine is a newcomer in this field and while it was successfully applied to the *Augustus* of 32,000 tons it does not as yet seriously threaten the turbine for very large vessels. The same may be said for the electric drive for, while it is applicable to large ships, only a few installations have been made. The introduction of oil fuel, as has been noted, is a major advance in marine propulsion whether used as a fuel under steam boilers or burned directly in the Diesel engine.

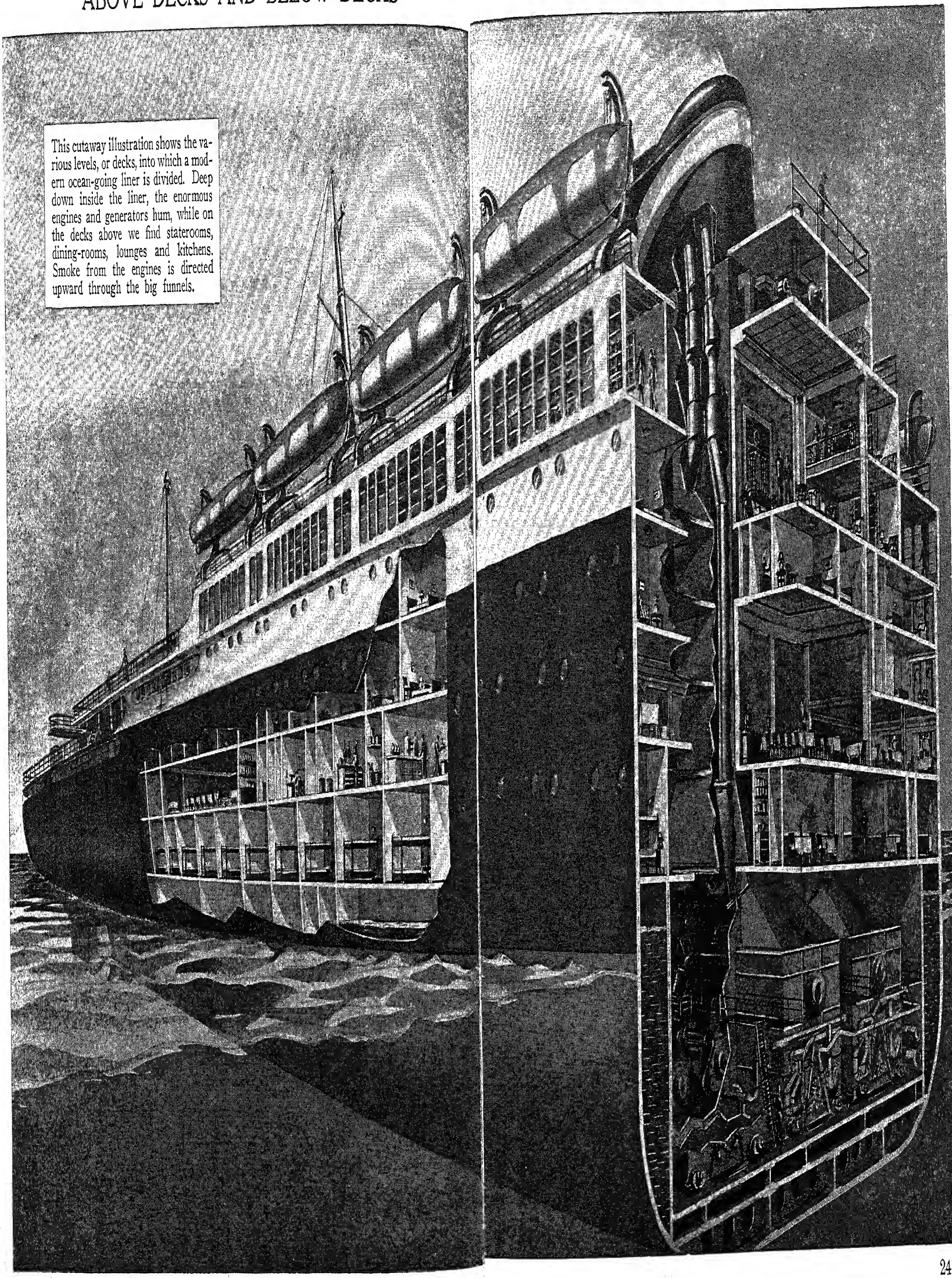
The data given in the accompanying table are not to be taken as exact. It is difficult to obtain exact figures since tonnage and length are defined in two ways and records do not always discriminate or agree. Horsepower and speed as given are, generally speaking, the builder's estimates and not the result of trial trips. However, these are accurate enough to present a fair picture of progress.

It will be noted that the real struggle for the "Blue Ribbon of the Seas" began shortly after 1900 and in the beginning was confined to the British and German builders. The Germans went after it with the *Deutschland* of 23 knots. The British brought out the *Mauretania,* perhaps the most famous steamship ever built, in 1908 with a speed of 24.5 knots. Germany then built a number of big, fast liners including the *Imperator, Vaterland* and *Bismarck.* These she lost during the war and they were renamed *Berengaria, Leviathan* and *Majestic.* The World War I stopped all such activities, but at its close Germany came back with the sister ships *Europa* and *Bremen* which have held the New York-Europe record, though by a small margin, over the old *Mauretania.* The French entered the race with the *Ile de France* in 1926 and the Italians came into it with the *Rex* in 1932. Then the French built the *Normandie,* which was 1,029 feet in length; the *Queen Mary,* constructed by the British, was 1,020 feet long. In the days before World War II, both these ships won the mythical blue ribbon for record speeds.

On the *Normandie* every known navigation device that had been developed for the safety and for the careful handling of a modern liner had been installed on the bridge. It was divided into four parts, the bridge proper, the chart room, the bridge wings and the upper bridge.

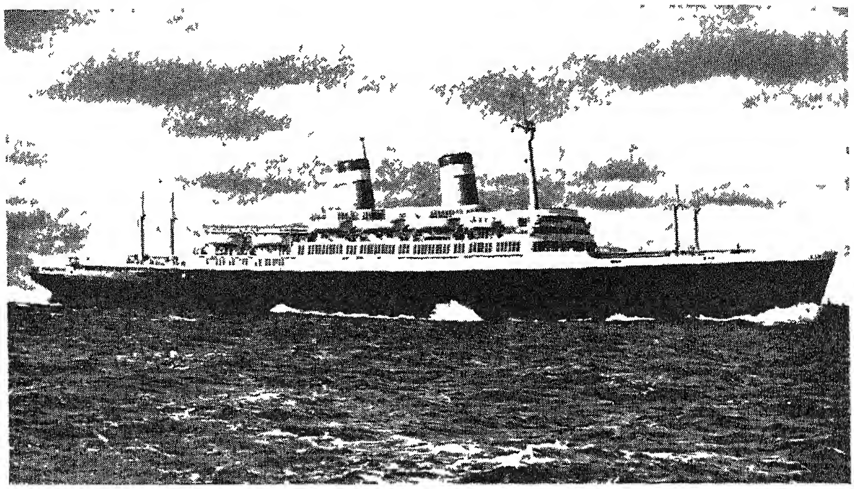
The bridge proper of the *Normandie* was a vast inclosed area 72 feet wide in the center of the forward end of the superstructure on the sun deck; it communicated with the bridge wings on either side by large sliding doors. The glass-inclosed forward part was streamlined in a semicircular design in order to lessen wind resistance. The large windows of the bridge were of shatterproof glass. So were the revolving circular ports which were electrically driven at a constant high speed. They afforded a clear view in spite of rain, snow or spray through the action of centrifugal force.

ABOVE DECKS AND BELOW DECKS IN A GREAT OCEAN-GOING LINER



This cutaway illustration shows the various levels, or decks, into which a modern ocean-going liner is divided. Deep down inside the liner, the enormous engines and generators hum, while on the decks above we find staterooms, dining-rooms, lounges and kitchens. Smoke from the engines is directed upward through the big funnels.

A CRACK AMERICAN LINER



The Independence is a transatlantic liner that incorporates the latest ideas in comfort and safety.

Both photos, American Export Lines

The luxurious lounge of the Independence. Hidden lighting fixtures provide even, non-glare lighting.

The chief items of apparatus in the inclosed bridge were.

The engine room telegraphs to the four electric engines of two different types, allowing a control of the transmission.

Two gyroscopic compass repeaters for the watch officers and two other repeaters for the helmsman.

The automatic gyropilot, which, when once set, automatically keeps a liner on her course without the physical aid of a helmsman, who, nevertheless, is always on duty at his station behind it.

A hydraulic telemotor rudder apparatus.

A rudder angle repeater indicating the exact position of the rudder.

Telephone loud-speakers, French type, for communication from the bridge to the engine room, the navigation bridge and the forward and after bridges.

Telephone apparatus connecting the bridge with the captain's quarters, officers' quarters and the central fire department station, located in the passenger section.

Two automatic sounding recorders, both of French design.

The *Normandie* was equipped with two electric "logs," which registered its speed.

During World War II, the *Normandie* was bought by the United States as a troopship and renamed the *Lafayette*. On February 9, 1942, the vessel was partially destroyed by fire at her pier in New York City. The liner was later scrapped.

The *Queen Elizabeth,* largest of the world's ocean liners

The year 1940 saw the maiden voyage of the *Queen Elizabeth,* the world's largest liner. Sister ship of the *Queen Mary,* it is 1,030 feet long, 118 feet wide, and has a gross tonnage of about 85,000. It has facilities for accommodating about 2,300 passengers. The speed is approximately that of the *Queen Mary,* about 32 knots. Unlike the latter, it has only two funnels due to improvements in the design of high-pressure boilers. The promenade deck of the *Queen Elizabeth,* 724 feet long, is almost entirely glass-enclosed, except for a few feet of open space at the aft end. From the keel to the top mast of this vessel is a height of 234 feet. During World War II many of the great ocean liners became troop transport ships. They did yeoman service in carrying troops rapidly to the different theaters of war.

Some of the world's fastest ships and their established records

It may be of interest to note what new ships must do to beat established records A few of the most noteworthy and the fastest records follow It should be remembered that the eastward passage is, in general, quicker than the western because prevailing winds are eastward

1819	Savannah	26 d– 0 hr– 0 m
1838	Sirius	18 d–12 hr– 0 m
1838	Great Western	15 d– 0 hr– 0 m
1840	Britannic	14 d– 8 hr– 0 m
1900	Deutschland — New York to Plymouth	5 d– 7 hr–38 m
1910	Leviathan — New York to Cherbourg	5 d– 6 hr–21 m
1929	Mauretania — New York to Plymouth	4 d–17 hr–49 m
1929	Bremen — Cherbourg to New York	4 d–17 hr–24 m
1930	Europa — Cherbourg to New York	4 d–17 hr– 6 m
1932	Bremen — New York to Plymouth	4 d–14 hr–30 m
1933	Rex — Gibraltar to New York	4 d–13 hr–58 m
1952	United States — New York to Bishop's Rock	3 d–10 hr–40 m
1952	United States — Bishop's Rock to New York	3 d–12 hr–12 m

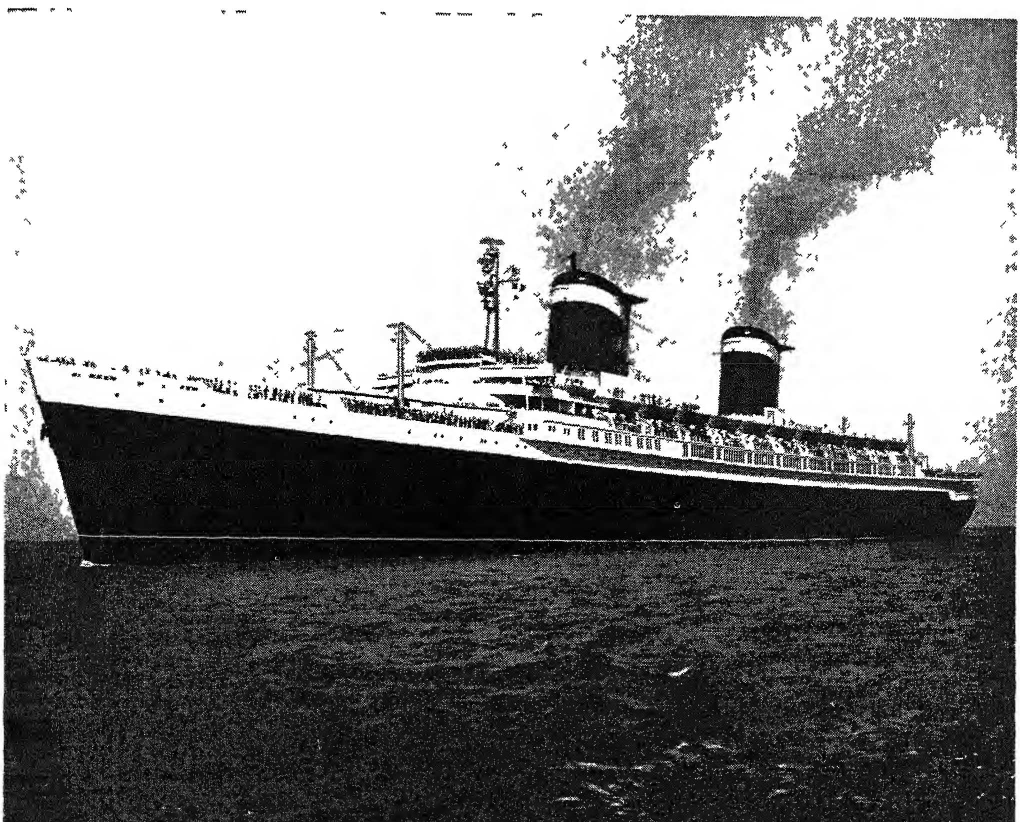
The comparative speeds of recent superliners

The best average speed of the *Bremen* and her sister ship the *Europa* was about 27.8 knots. The *Rex* while running over a different course is credited with an average of 28.92 knots. The *United States,* on her first eastbound Atlantic crossing, set the new transatlantic speed record by averaging over 35 knots. The tremendous horsepower needed to push a giant vessel well above 30 knots should be noted. Thus the power required to drive a given ship through the water varies as the cube of the speed If, therefore, it requires 150,000 horsepower to propel a ship from Cherbourg to New York in four days it would require $(150{,}000 \times 4^3) \div 3^3$ or 355,555

horsepower to propel the same ship over that distance in three days.

In July 1952 the *United States,* largest ship ever built in the Western Hemisphere, made its maiden voyage and, as we have seen, proved itself the fastest passenger vessel ever set afloat. From stem to stern it measures 990 feet. It is a slim 101½ feet wide, permitting passage through the Panama Canal, carries two stacks towering 175 feet above the keel and weighs 53,290 gross tons. It can accommodate 1,982 civilian passengers and a crew of 1,000. The ship has specially built-in military features enabling rapid conversion into a troop transport. The construction is entirely of steel, aluminum and other nonflammable materials to guarantee that this vessel will never suffer the fate of the *Normandie.* A vast system of watertight compartments protects it against sinking by a single bomb or torpedo or by collision. There is air conditioning throughout the ship from bridge to engine room; the passenger can adjust the ventilation and temperature of his own stateroom to suit his desire. Each passenger room has a telephone for rapid ship-to-shore communication. With such features the *United States* provides a rapid, safe and luxurious passage for all those aboard.

The reader is left to draw his own conclusions as to how large and how fast the big transatlantic liners of the future may be, bearing in mind the possible utilization of atomic power. As to speed, ocean liners will never compete with the air liners that serve in transoceanic travel. But because of their great capacity and the many services they offer, ships will probably always be an important factor in sea transportation in the years that lie ahead.



U. S. Lines

The good ship *United States,* pride of the United States Lines, is the fastest ocean liner afloat.

CANADA'S REINDEER EXPERIMENT

Why This Antlered Animal is so Valuable in the North

THE ESKIMOS' BEAST OF BURDEN

WHILE the domesticated reindeer was introduced into North America only very recently, the breeding and grazing of reindeer is an industry of long standing in arctic and sub-arctic regions of the Old World. It is definitely known from Chinese annals that, in A D. 499, they were employed in north-eastern Asia as draught animals and beasts of burden, and that the milk of the females was extensively used; so that domestication must even then have been an established fact Marco Polo, in the latter part of the XIII century, speaking of a tribe of Asiatic nomads that lived near Baikal Lake, evidently refers to reindeer breeders when he remarks· "They are a wild race and live by their cattle, the most of which are stags, and these, I assure you, they used to ride upon".

Although authors disagree as to the exact center where domestication originated, it has generally been agreed that the country east of Baikal Lake, Transbaikalia, was probably the earliest home of the tamed reindeer By stages the industry moved westward through western Siberia, Russia, Finland and northern Scandinavia. From the last comes the earliest reference to European tame reindeer. It is contained in the narrative of the famous Viking Ohthere, a contemporary of Eric the Red, the discoverer of Greenland, and the father of Leif Ericson, who discovered America five hundred years before Columbus. Ohthere told his lord, King Alfred, that he "dwelt farthest north of all Northmen", and that on his estates in Norway he owned more than 600 tame reindeer. He had obtained these, he said, during his extensive travels, when he rounded the North Cape and followed the Murman Coast and finally discovered the White Sea

As late as 1891, upon the recommendation of Dr. Sheldon Jackson, United States General Agent of Education in Alaska, the United States Government introduced the first reindeer into America, bringing that year as a relief measure for the then famishing Alaskan Eskimo a small herd from Siberia

So congenial did the physical and climatic conditions, so closely resembling those of regions occupied by them in the Old World, prove to these newcomers that, from the comparatively insignificant number of 1,280 animals introduced between 1891 and 1901, in 1941 Alaska had approximately 205,000 head of reindeer. The natives in 1941 owned an estimated 161,000 and the Government 44,000; a total of 3,190 Eskimos, Aleuts, and Indians owned shares of stock in the native reindeer associations.

The typical reindeer of Alaska (*Rangifer tarandus*) is considerably darker colored than its native cousin, the caribou. Its neck and shoulders are grayish white, becoming darker over the back and rump, shading gradually into much darker sides, abdomen and hindquarters. The legs are short-haired and much darker than the rest of the body. Around the tail there is a white, or light grayish, patch which descends between the legs. The head also is dark, except the nose or muzzle, which is light gray. The front of the neck is covered by a mane, which grows long in the winter, and is usually almost white.

The hair, shed annually in the early part of the summer, turns much lighter in October when the snow comes, and is considerably longer in winter than in summer

A full grown Alaskan bull stands a little over fifty inches at the shoulders and measures about seven feet from nose to tip of tail The adult female is somewhat smaller and of a more slender and graceful build.

Climate has a decided effect on the development of the animals In the temperate climate of southwest Alaska, the average three-year-old steer dresses from 150 to 200 pounds; steers from the Point

ALASKAN REINDEER HERDER

Barrow herds seldom scale 100 pounds, and a large number have been found to average less than 80.

The genus *Rangifer* has the distinction of being the only member of the deer family in which both sexes have horns or antlers. Those of the full grown bull are very large and may weigh more than 45 pounds, while those of the doe are slender and more gracefully shaped, and, besides, have fewer points. Like the rest of the family, the reindeer shed their horns annually. The adult bulls drop theirs shortly after the rutting season is over, and by Christmas nearly all are without horns. The yearling bulls retain theirs till late spring and the females until the fawns have been born in April and May. To the female the horns then serve as a means of defending her offspring against enemies. The hornless bulls and steers segregate from the yearling bulls and females before the beginning of the fawning season, and do not rejoin the does until late in the summer The antlers are not, as commonly believed, used to scrape away the snow and uncover the moss, but are used exclusively as a means of attack or defense.

The common belief, also, that "reindeer live exclusively on moss" is erroneous On the contrary they are rather catholic in their choice of food, and in the summer will eat almost anything that is green. Lichens, commonly known as "moss" or "reindeer moss", are eaten only incidentally, except when wet and spongy after rain, but they are very fond of mushrooms and will frequent places where they grow Their insatiable craving for salt, or anything that is salty, has long been known and made use of by nomads On the range they greedily devour dead mice or birds found on the tundra, and never pass up a nest containing eggs. For this reason, since their introduction, the ptarmigan has been decreasing in Alaska During the winter they feed almost exclusively on lichens, nearly all species of which they find palatable, but only those fruticose species that occur in great abundance in arctic and especially sub-arctic climates, and attain their best development at some distance from the sea, are of economic importance. Species of the three genii *Cladonia*, *Cetraria* and *Stereocaulon* probably furnish 90 per cent of the "moss" consumed by the reindeer

For winter traveling over the snow-covered, roadless arctic tundra, the advantages of the reindeer over the dog as a draught animal are manifest. The reindeer feeds itself, while the dog must be fed by its master, and, where game cannot be procured *en route*, dog feed must be hauled on the sled. The maintenance of a dog team, even to the native, often becomes a burdensome task.

Dr. Sheldon Jackson, in one of his reports to the United States Government,

says: "As soon as the wind blows a little, the dogs cannot travel; especially is this so if the wind happens to be in the face. The reindeer does not mind the wind in the least, from whatever direction it comes; it rather enjoys traveling against the wind It costs nothing for feed, it faces all weather, and makes its way where the driver can hardly walk without snowshoes.

ALASKA REINDEER STEERS WITH THE HORNS IN VELVET
These deer have been broken in to a grain and hay diet previous to appearing in Seattle as Santa Claus' team.

It goes uphill and downhill alike Trail or no trail, it will haul its two hundred pounds or more day after day, even week after week."

In Alaska, where the reindeer industry is still young, dog driving still holds supremacy, and only where dog feed is scarce can the reindeer, at present, successfully compete with the dog for winter traveling. In the arctic regions of the Old World, however, the reindeer has been used almost exclusively for ages for cross country traveling In Siberia, Russia, and in Lapland, it is still the most common means of winter conveyance

While the reindeer may be said to be truly in a stage of domestication, man has never attained such complete control as has been achieved with other domestic animals, such as cattle or horses. As the Laplander Johan Turi very aptly remarks: "The reindeer does not follow man, it is man that follows the reindeer". Although under domestication probably for at least two thousand years, they still more or less live the life of their wild brothers — the caribou — and will probably always con-

tinue to do so. The reindeer requires no stable or shelter, either from the rigor of the arctic blizzard, or from the hot blast of the summer sun; it remains more or less independent and, between the annual or semi-annual round-ups, follows its natural instincts in the matters of nutrition and breeding In other words, it lives its own life with but few modifications, such as to answer its master's call when occasion arises to pull his sled, or, as is most often the case, to supply meat for the pot or skins and sinew for his clothing

The reindeer industry is rather narrowly bound to a well defined geographical area having definite floristic characteristics, and

ALASKAN REINDEER HERDER WITH HIS SLED DEER

it cannot be transplanted to other zones. Reindeer held in parks or zoological gardens, even if provided with their natural feed, do not thrive, and are usually doomed after a few years of captivity. Experiments along this line, where whole herds have been transplanted from their natural environment, have failed in Switzerland, and, on this continent, in the State of Michigan and in the Province of Quebec The reason for failure has not been due to the absence of their natural food, but to the fact that climate and surroundings were not congenial to their continued welfare. The reindeer will always retain its migratory habits and never reach a state of true domestication.

Of late, conditions somewhat similar to those that existed in Alaska fifty years ago, have developed among the Eskimos in certain parts of arctic Canada As a natural consequence of the ever-increasing demand made upon the pelts of the fur-bearers of the North, during the last decade or two, a chain of trading posts has been established across the country from the Yukon-Alaska Boundary along the shores of the Arctic Ocean to the east coast of Baffin Island This establishment of trading posts has greatly changed the economic habits of the Eskimo In order to procure such highly desirable things as rifles and ammunition, power-boats and gasoline, phonographs and many other commodities without which he was able to get along nicely before, he now has to trap foxes, because the pelt of white fox is practically the only article produced in the far North, which is of commercial value

Nearly all game animals of the Arctic are more or less migratory, and the Eskimo, therefore, before the advent of the white man, migrated with the animals on which he depended for a living At certain times of the year he hunted seals far out on the frozen sea, in the spring, when the fish came to the rivers to spawn, he abandoned the seal hunt and came to the rivers in order to put up fish for the following winter, and in the fall, when the caribou migrated south to spend the winter near the edge of the woods, he followed them inland until sealing again became profitable on the ice.

The change from hunter to trapper has not only changed the seasonal movement of the Eskimo, but since he now has to hunt foxes during the time he should be engaged in catching seals or hunting caribou for meat and clothing, he must now go to the trader to obtain the white man's inferior substitutes for them.

The passing from an exclusive meat and fish diet to one composed of badly cooked bread, jams, tea and canned foods; and from the fat of the caribou or the blubber or oil of the seal to substitutes, poor, or entirely lacking, in vitamin, such as lard or vegetable shortening; and from his own sensible and adequate skin apparel, to the imported clothing and bedding of the white

SPRINGTIME SMILES ON THE ARCTIC

CLOSE-UP OF A BIT OF ARCTIC PRAIRIE NORTH OF GREAT BEAR LAKE

Soon after the snow has disappeared the ground is covered with beautiful flowers.

Photo R C A F. Station, Ottawa

REINDEER TRANSPORT DEER IN HARNESS AND LOADED SLEDS, NORTHWEST TERRITORIES

man, has been far from beneficial to the Eskimo. It has lessened his health and vitality and has lowered his resistance against contagious diseases

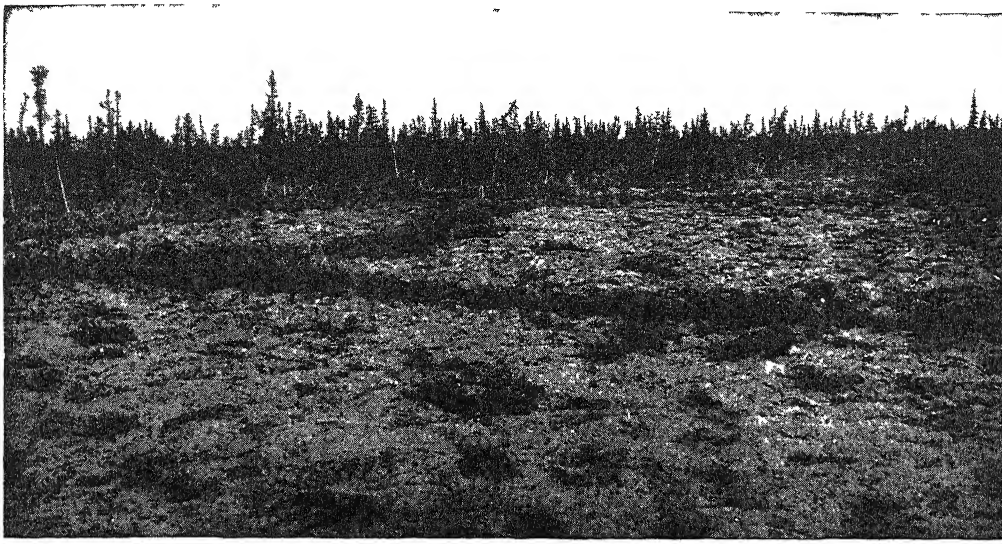
The effect on hunter and hunted of the introduction of modern firearms

To the indigenous game of the Arctic, the introduction of modern firearms and unlimited ammunition has been a serious threat It is true that the Eskimo and Indian no longer entirely depend on the native game for their food supply, but it must be remembered that, in the earlier days, the hunting with the bone-arrow and harpoon involved so much hard work and wearisome stalking that seldom was more game killed than was actually needed. Now hunting has been made so much easier that the Eskimo often kills more game than his requirements warrant.

In Northern Canada the wild-life conservation policy of the Department of Mines and Resources has been consistently directed to offsetting these many influences by the establishment of preserves and by the education of the native Indians and Eskimos. The reindeer project in arctic Canada, due to the success of this industry in Alaska, is a step in the development of this policy. Before incurring the expense involved in the introduction of reindeer on a large scale, however, it was decided to make a very thorough investigation of the area into which they were to be introduced. The first part of this investigation was undertaken in 1926-28 and covered the country between the Alaska-Yukon boundary to the west and the Coppermine River to the east. This area has for its northern boundary the Arctic Ocean and to the south reaches well into the sparsely wooded land which extends some distance north of the great transcontinental coniferous forest.

The ideal territory selected for the Canadian reindeer experiment

This vast territory, which comprises more than fifty thousand square miles, is all fairly low, rolling, prairie-like country. Open spruce forest is found along its southern boundary, but the greater part is covered with short grass, and with mosses and lichens and small flowering plants, while patches of sedgy or peaty soil occur at irregular intervals. In the low valleys, as well as along the banks of river and lake, heath and moor appear on which Labrador tea, arctic white heather, crow and a few other kinds of berries, dwarf birches and willows grow in great profusion. Near the Arctic Ocean reindeer moss is not found in great quantities, but some distance from the sea and the cold sea fogs, its white and gray, coral-like species forms a dense, soft carpet around the heather and dwarf trees of the arctic prairie. In this type of country, it requires forty-five acres to feed one reindeer all the year round. The first 2,370 reindeer were taken from one of Alaska's best herds.



ALMOST PURE PATCH OF "REINDEER MOSS" NEAR THE DELTA OF THE MACKENZIE RIVER

Finally, when the quota was filled, the caravan started on its long trek shortly before Christmas At its head walked a small, oldish man on skis, clad from head to foot in reindeer furs, his beardless face darkened and weather-bitten from a life-long exposure to icy winds and drifting snow An observer thus describes the scene· "From under the shaggy eyebrows a pair of pale gray, but extraordinarily keen

WINTER PASTURE FOR REINDEER IN ARCTIC CANADA
In the Mackenzie district near the edge of the woods, at some distance from the sea coast, "reindeer moss" grows in great profusion. In a stand like this an area of one square yard will yield more than a sack full.

eyes scan the low, rolling, almost featureless tundra ahead. Turning towards the south he decides, from the position of the sun, that the time has come to call a halt He sits down on a snow-drift and watches with satisfaction the slowly advancing train behind him. And well may he be pleased with what he sees! Unfolded to his vision is an imposing herd of 2,370 head of reindeer—probably the largest and most spectacular movement of reindeer that has ever been undertaken in historic times. Fifty trained sled deer, each hauling a load of about two hundred pounds of camping outfit and provisions, constitute the commissariat of the expedition and make up the van. Behind follows the long, long string of deer, walking abreast in groups of five or six. Now one stops to nip at the top of a tuft of dead grass, which protrudes above the snow, and now again starts off in a smart trot to catch up with the rest. . . . As the herd moves, the jingling of many large bells is heard from afar. These bells were placed on a number of select animals and serve a two-fold purpose: to drive away wolves and other predatory animals, and to make it easier for the herders to locate stray animals in the darkness or when the visibility is low on account of snowstorms or blizzards.

"The old man who is leading and who is in charge of the drive, is Andrew Bahr. He was born and raised at Kautokeina in northern Norway, in the province of Finmark. He is a Laplander and a born reindeer man, as his ancestors have been before him for countless generations. He came to Alaska many years ago, as a young man, in charge of a herd which was brought all the way from Kautokeina. Later, he obtained from the United States Government the loan of a small herd of one hundred deer. This, under Bahr's expert management, increased wonderfully, and, after returning, in the course of a number of years, the original stock, he held in his own right one of the largest individually owned herds in Alaska. When some years ago he sold his entire herd, he found himself a wealthy man. Not knowing exactly what to do, he bought a property near Seattle, Washington, which would easily take care of his needs for the rest of his days. But Andrew was not happy in Seattle, and when the proposal was made to him to take a herd of reindeer from Alaska to Canada, he at once accepted and returned to the North."

Bahr was accompanied by three other Lapps and six young Eskimo reindeer boys. Wherever a reindeer man goes, he takes his dog with him, for he knows that "a good dog is often worth four herders" when it comes to bringing stray deer back to the main herd, and the personnel of the expedition is accompanied by seven small reindeer dogs. Nature has not furnished some of these dogs with a natural fur coat suitable for such a trip, so their masters have found it necessary to provide one made to order from reindeer skins. At night each dog is usually to be found in the warmest part of his master's sleeping-bag.

During the previous decade reindeer herds in Alaska had increased so tremendously in size, some even up to 20,000 head, that the control by herding had become much less effective, since each animal was handled less frequently, and the mode of life of the animals gradually approached that of the wild caribou Progress therefore was slow at first as every precaution had to be taken to prevent small bands breaking away from the main herd. It was arranged that the first few months would be occupied in taming and accustoming the deer to the routine of the drive and in the training of a large number of sled deer. Many times during the initial stages of the round-ups the herders found themselves foiled, and weeks of hard work and painstaking driving were frustrated, when, during a snowstorm, or through a false move of some of the helpers, part of the herd broke away and returned to the range whence it had started weeks before.

Such occurrences, however, are not at all unusual in reindeer herding, and do not in the least discourage the experienced reindeer man. Where a white man would give up in despair, the Lapp or Eskimo merely laughs and begins all over again. Time is of little consequence to these people, so long as the "grub" box is full and the sleeping quarters fairly comfortable.

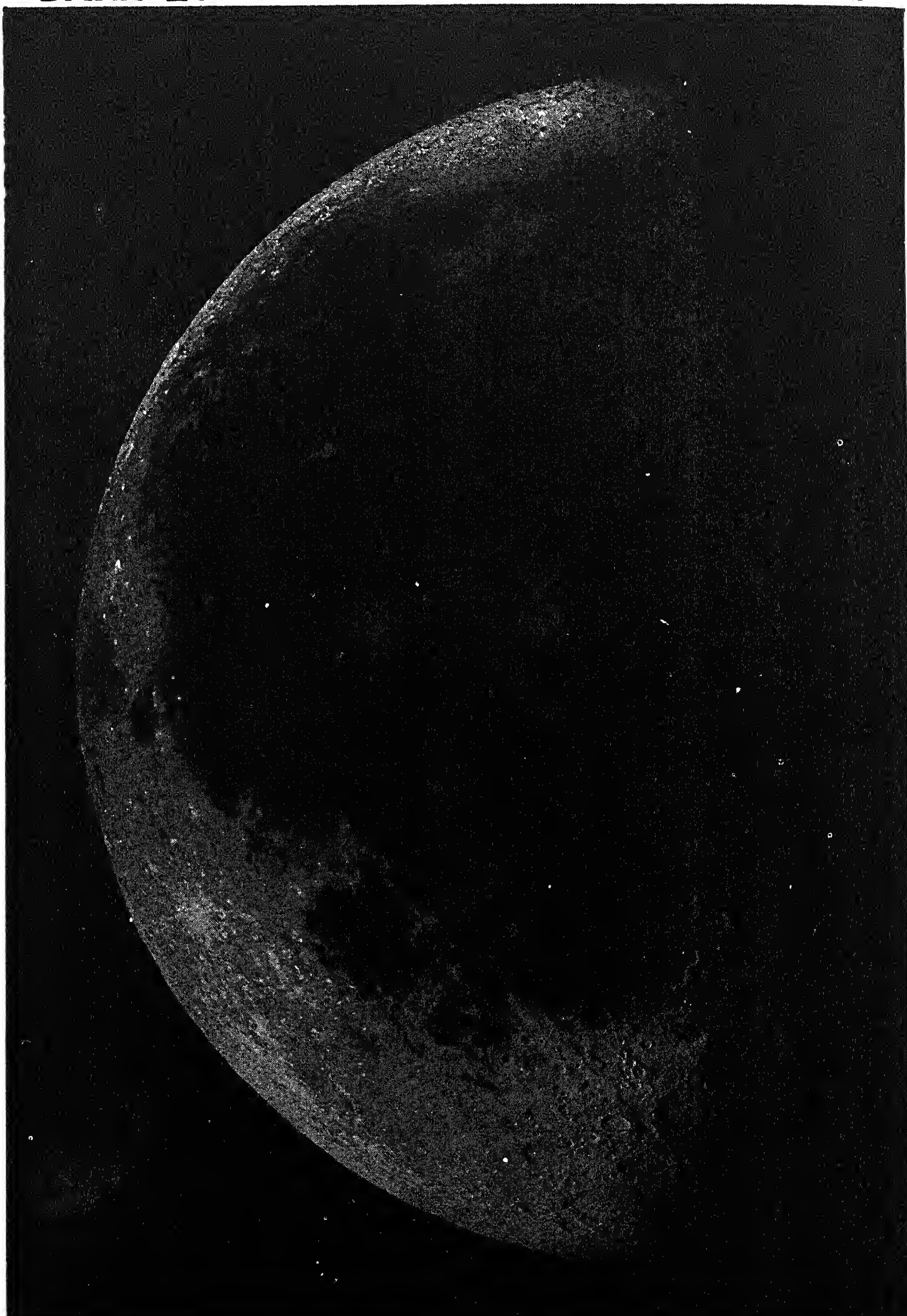
CAMP ON THE NORTHERN PLAINS, NEAR THE COPPERMINE RIVER
Splendid reindeer pasture with a good mixture of browse and "moss".

Since March, 1935, when the reindeer were introduced to the reserve in Canada, excellent results have been obtained. Annual crops of healthy fawns have assured a steady increase in numbers, permitting the establishment of two additional herds under native management near Anderson and Horton rivers, about 150 miles east of the reserve. The total increase of the reindeer over the original number has exceeded 12,000, and according to 1942 reports the three existing herds amounted to more than 9,000. The balance is accounted for by sales of meat to natives and residents; donations to schools, hospitals, and missions; animals used for food and clothing by the reindeer staff, including herders and apprentices; strays; and losses from natural causes.

The form of herding practised on the Canadian range requires the presence of herders with the reindeer at all times. Each herd, which has been allotted distinctive ear markings, is maintained in a separate location. This is known as "close herding" as distinct from "open herding" which is followed to some extent in Alaska where reindeer with different markings roam together over the range and are counted at a general roundup in which the various owners take part. As the natives possessing reindeer herds gather helpers to assist in herding, it becomes possible for them to take part in other activities such as trapping, hunting, fishing, visiting, and fraternizing with friends and travelers, without neglecting the herds.

Reindeer are providing a convenient and dependable source of food and clothing and form a valuable reserve against periods of shortage in other necessities. As the natives learn to depend more and more on the herds of reindeer for subsistence they will become independent of fluctuations in the supply of game and price of furs, and thus achieve a more stable economic life than is possible under ordinary conditions which govern their nomadic life along the Arctic coast of Canada.

DARK LUNAR SEAS AND SHINING CRATERS



VIEW OF THE MOON WHEN TWENTY DAYS NINETEEN HOURS THROUGH ITS MONTHLY CHANGES
From a photograph by M. P. Puiseux at the Paris Observatory.

THE SURFACE OF THE MOON

Its Craters, Mountains, Level Plains, Valleys and Ray-like Brightnesses, with Conjectures as to Their Causes

THE UNIVERSE AS SEEN FROM THE MOON

THE craters of the moon cannot be seen by the unaided eye. They were discovered in 1610 with the aid of the newly invented telescope, by Galileo, who described them accurately as ring-like mountains around depressions, and even attempted to measure their altitude, arriving at an estimate very much the same as that which is held today. The height of both the crater walls and other elevated features on the moon's surface is determined by measuring the length of the shadows they cast on the moon's surface.

Many theories have been brought forward with regard to the origin of these pits scattered so freely over the greater part of the moon's surface. On the side turned toward the earth there are more than 30,000 craters which have already been observed. At the present time there are only two theories concerning them which astronomers regard seriously. One of these is the volcanic theory and the other the meteoric, both of which we shall discuss fully later on. First, however, it might be interesting to see what some of the older theories are like.

One theory which formerly had many supporters was that the craters were the remains of broken bubbles formed in highly tenacious molten lava on the moon. Broken lava bubbles do produce an appearance strikingly similar to that of the lunar craters, except for the fact that they do not produce the central cone which is so characteristic of the lunar craters. Today, however, for many reasons, this theory of the origin of lunar craters is not at all acceptable.

Another view holds that each crater is due to a very limited but very powerful explosion within the materials of the moon's surface, acting equally in every direction, and so throwing up a circular rampart of lava that cooled into the form we now see. This view fails, not only because of the great regularity of the craters, but also because of the steepness of their walls, which have an average slope of forty degrees on the outside, and even more on the inside. Vast masses of lava thrown up in a molten condition into prodigiously high walls of such steepness would certainly not cool and solidify in that position.

A third conjecture is that the craters are the result of local whirpool movements in the molten materials of the moon's surface, during the process of solidification. A fourth holds that the site of each pit was formerly a lake of water fed by hot springs, and that the moisture, evaporating from the surface of the lake, was precipitated as snow all round it, thus building up circular walls of ice which remain to this day as the crater walls. Neither of these theories is really tenable. As against the latter, it may be pointed out that ice not only evaporates or sublimes even at low temperatures, but it also flows, though slowly, as we know from the glaciers of the earth: hence these supposed walls of ice would have been flattened out ages ago.

A fifth theory, and one which has perhaps more supporters today than any other, suggests that the lunar craters were probably formed by the impact of many meteoritic particles falling on the moon. Much evidence supports this theory.

There are various other theories about the formation of the moon's craters. But these conjectures are so fanciful that they may well be set aside until we have exhausted the possibilities of simpler and more probable explanations.

The meteoritic theory of the formation of the moon's craters

The meteoritic theory is that giant meteorites must have struck the moon millions of years ago at a time when its surface was relatively soft and plastic, and that the surface of the moon still shows the marks of this invasion from outer space. Since there is no atmosphere and no water on the moon, there would be no erosion to efface the marks left by the impact of the meteors. This ingenious theory has been illustrated by certain striking observations. Thus, clay pellets shot into a clay surface will produce markings upon that surface strikingly like those of the lunar craters; raindrops falling on mud produce much the same effects.

Objection to the view that the craters were formed by meteorites

There are certain objections to the meteoritic theory, and until they have been answered satisfactorily, the theory cannot be accepted without reservations. The principal objections are as follows:

First, a mass entering the moon's surface at so great a velocity would generate a great deal of heat and would melt down any crater walls that it might throw up; it would also melt down a considerable area of the surrounding regions.

Second, not all the masses thus striking the moon would fall vertically upon it—yet all the pits are exactly vertical.

Third, if the moon were formed by the coalescence of separate masses, as may very well have been the case, the smaller bodies must have been the first, and the larger, having greater independent momentum, the last to join. But the largest pits were the first and the smallest pits were the last to be formed, as is shown by a great number of instances where the crater walls of two pits of different size intersect one another.

And, finally, this meteoritic theory, like most of the others that we have mentioned, fails to account for the steepness of the lava walls. Notwithstanding the comparatively slight effect of gravity on the moon's surface, there is no ground for believing that lava, thrown up in the molten condition into walls of such mountainous elevation, could cool and solidify so suddenly as to retain that form.

The theory that the craters were formed by volcanoes of a quiet type

The theory that the craters were formed by volcanic action is still held by certain scientists and it deserves careful consideration. Now we know that on earth there are two different kinds of volcanoes—the eruptive and the quiet. The former, including such as Vesuvius, Krakatoa and Mont Pelée, are by far the more frequent. From time to time they discharge steam and scorching gases, bury surrounding districts in ashes, or pour forth devastating streams of lava and have thus caused some of the most dreadful disasters in history. It is certain that the volcanoes of the moon have not been of this type. But their craters resemble in the most striking way the craters formed on earth by quiet volcanoes, by which we mean not eruptive volcanoes in a quiescent or extinct condition, but an entirely distinct kind, which are much less generally known because they are less numerous, more remote and less sensational in their performances than the volcanoes of the eruptive type.

The largest of this kind are in Hawaii. This island in the Pacific, eighty miles in diameter, and rising to a height of 14,000 feet above the sea, or 30,000 feet above the sea bottom, has been built up by the activity of four quiet volcanoes.

A volcano on the earth that is probably like those on the moon

Mauna Loa, one of these craters, is three miles in diameter, and has a depth of 1,000 feet; and when inactive it has a hard floor of solid lava upon which it is possible to walk. When eruptions occur, the floor rises, its cracks open into fissures through which lava spouts and streams, and the

crater becomes a lake of molten lava whose surface rises until it quietly overflows the rim of the crater, or escapes through rifts in the mountain side. The effect of an eruption is generally to enlarge the crater; to build up the outside of its walls by the streams of lava which pour down them, and, on occasions when the molten lava overtops the rim, to build the walls still higher. After eruption the level of the lava sinks in the crater, and a new floor is formed by the cooling of its surface. These eruptions are slow, gradual and silent. Kilauea, another crater in the same island, and of nearly the same diameter, behaves in an identical way, except that in this case the central cone, which is so characteristic of the craters of the moon, has been observed. A cone, four hundred feet in height, containing a lake of molten lava, was built up during a few years from the center of the crater floor. Indeed, the craters of these quiet volcanoes of Hawaii resemble those of the moon in every respect in which they can be compared, except that the lunar craters are in many cases much larger.

One way in which lunar craters might have been formed

There is reason to believe that at an early stage in its history the moon was a globe of viscous consistency, much closer to the earth than at present, rotating much more rapidly on its own axis than it now does, and revolving also round the earth.

The surface of the moon, under these conditions, must have been subject to tides of immense force; and as the surface began to cool sufficiently to solidify into a thin crust, this crust, contracting round its contents, must have been easily cracked at any points of weakness by the force of these enormous tides. Some astronomers have believed that the liquid material within the body of the moon, issuing forth at these fissures, might have formed craters of the type described above. The larger and older craters would have been formed in earlier stages of the moon's solidification, and the smaller craters at a later stage.

In accordance with this theory, we find that the linear arrangement of the more ancient craters, in so far as they have any is mainly in the north and south direction, or, plainly, the direction in which these powerful tides would rend the crust; and we find also that the smallest and most recent craters are developed in lines and series, sometimes hundreds of miles long, lying along obvious cracks in the surface, which often radiate from the sites of the more ancient pits.

Is there volcanic activity on the moon at the present time?

The question has often been raised whether there are any signs of volcanic activity going on at present in the moon. While many authorities deny any such activity, Neison long ago pointed out the inadequacy of the reasons adduced for this denial, and more recently Pickering's observations have given strong positive support to the actual occurrence of physical change: it is true that some of the alleged cases of physical variations in the moon's surface may find a sufficient explanation in the changing appearances caused by variations in the angle and direction of the sun's rays, but this explanation is scarcely admissible in all the cases cited by Pickering and others. One of the most remarkable instances of alteration in the moon's surface took place in the crater named Linné; this was formerly six miles in diameter, and had clearly marked steep walls, but was discovered in 1866 to have undergone great changes, so that instead of the old crater there was a white spot more than ten miles in diameter, within which there was now a very small crater. Of course, the rocks of crater walls, subjected alternately to the fierce heat of the sun and to the great cold of the lunar night, cannot but be affected by the consequent expansion and contraction of their materials, so as to be ultimately broken down Linné may have been in a very unstable condition, and may then have been shattered by the blow of a meteor, filling the crater with the exception of a narrow space in the center. Possibly, on the other hand, the earlier observers

may have measured and drawn it incorrectly. But to many astronomers it still seems more likely that Linné is a structure whose appearance differs more than usual under different conditions of illumination. Certainly, observations of it in recent years have given varying results.

A classification of the lunar structures that are apparently volcanic

All the crater-like volcanic structures on the surface of the moon have been classified into six groups, chiefly according to their size, as follows: 1. "Walled plains", the vast craters surrounded by great walls, and often studded with pits of smaller size and later date. 2. "Mountain rings", the remains of similar huge craters, now seen in various degrees of demolition in the seas, or *maria*, which we have yet to study. These "mountain rings" are found only in the seas, and their differences from the first group depend only on that situation. 3. "Ring plains", the strongly walled pits, of great diameter, with steep inner sides to their walls. These differ from the first group chiefly in respect of the greater distinctness and regularity of their structure. 4. "Craters", the walled pits less than about fifteen miles in diameter. 5. "Crater cones", small pits, usually less than a mile in diameter, resembling conical depressions in the lunar surface. 6. "Craterlets", the smallest pits of all. It is necessary to mention this classification, as these terms are often used in descriptions of the moon's surface. But the several groups run into one another, and the classification is really arbitrary.

The irregular but roughly circular level plains or so-called seas, cover about a third of the visible surface of the moon, chiefly in the northern hemisphere. Each of them is vastly more extensive than the greatest of the craters. They are distinguished from the rest of the surface not only by their smoothness, but also, more conspicuously, by their much darker color. They are not by any means free from craters, but craters are much more sparsely scattered over the surface of the seas than over other regions; and those craters which occur on the seas are comparatively small, having diameters not exceeding ten or twelve miles, and are therefore probably of recent origin. The ruins of huge craters are, however, to be seen here and there within the seas.

The margins of the seas are not inclosed, like the volcanic pits, with mountainous rings; they resemble very closely the shores of real seas of water or of other liquid; the material forming them appears to have flowed in among the surrounding elevations, thus forming bays, or to have been limited in other places by gently rising ground.

Two conjectural accounts of the formation of the lunar seas

Where the sea's margin has come against the outside of a crater, it has sometimes melted away the crater's wall, leaving only a portion of the circle standing, and the sea has flowed within the crater; and in the same way, as we have already seen, the partially melted remains of great craters, which must have been formed earlier than the seas, may be observed in the midst of their area.

There are two chief theories with regard to the formation of the seas. One of them holds that each sea was formed by the impact of a huge mass, falling from space, upon the moon's surface. It can hardly be questioned that a collision of that kind might very well produce all the effects which we see. It would generate enormous heat, sufficient to melt the foreign mass itself, together with a large area of the surrounding country, thus forming a vast lake of very fluid lava which would melt down everything against which it flowed, until finally it cooled as a level plain of irregularly circular outline. On the surface of this plain, at a later date, the formation of craters would again begin, but the craters would, of course, be fewer, as well as smaller, than elsewhere.

The other theory has the advantage that it does not demand the fall of vast meteors out of space, but explains the formation of the seas in what is perhaps a simpler way. After a thin but compara-

tively rigid crust had been formed upon the surface of the moon, the contraction by cooling of the interior would require a corresponding contraction of the crust. But this crust was pitted with craters and honeycombed with cavities. It is suggested that in certain regions, where craters were exceptionally large and numerous, considerable areas of the crust may have fallen in upon the molten material below, and, being denser than the latter, because solid, may have sunk, or partially sunk, and so have become melted. In this way a fresh surface would evidently be formed. This sinking and melting of the crust has been seen again and again in the craters of the island of Hawaii.

Suggested reasons why the moon's "seas" are dark in color

The difference of color between the seas and the other portions of the moon is explained, according to this theory, on the supposition that, prior to the formation of any crust upon the moon, the materials of least specific gravity were presumably separated out, and floated upon the surface of the viscous globe; so that the crust, when formed, consisted of special materials, which were not only less dense but also of lighter color than those which underlay them. If, therefore, certain portions of the crust fell in, and a new surface was formed by the subjacent lava, this new surface, besides being smoother, would also be of darker color than the surrounding regions. It is consistent with this theory, also, that the surfaces of the seas, though not all at the same level, are all depressed below the level of the general surface of the moon.

The jagged mountain regions of the moon and their probable formation

The general surface of the moon is extremely rugged. In addition to the mountainous walls of the craters, the moon has many clearly marked mountain regions. These can hardly be called mountain ranges, because the peaks are massed together over wide areas rather than grouped in long chains. The mountain systems of the moon, which have received names from the terrestrial ranges, such as Alps, Apennines, etc., contain fragments of huge ancient crater walls, showing that the development of the mountains has been later than that of the largest volcanic pits. In regions where the crumpling of the crust has thrown up these confused areas of precipitous heights, the old ring walls have been broken up and their ruins have been elevated together with the surrounding surface. More recent and therefore smaller craters have in many cases been formed in mountain regions after the mountains had been built. Besides these high mountain systems of the moon, there are also ridges of slight elevation and narrow width, but of great length, on the surface of the seas. All the mountains of the moon are extremely steep, jagged and tumbled in appearance, and probably consist of masses of lava broken and thrust upward when solid, or extruded in a very viscous state from the interior.

The rills and valleys of the moon and the theories about them

The rills or valleys of the moon are clefts or cracks in its surface, having very steep sides and often are very deep. They are called valleys when they are wider, rills when they are narrower. Some astronomers have thought that the rills are series of minute craters so near to one another as to give the appearance of continuous lines, which often branch and may be several hundred miles in length, but the most capable observers give no support to this view. They regard them as simply cracks in the crust, formed by great pressure from the interior, after that pressure had ceased to be relieved sufficiently by volcanic action. The rills are therefore of comparatively recent date, and are probably the latest of all the structures formed upon the moon. At least a thousand of these cracks have been recognized and mapped, and there must be many thousand more.

There are, however, rills of a special kind which, according to some authorities, appear to have been river beds. These differ in four respects from the great majority of rills — namely, they are always

wider at one end than at the other; the wide end runs into a pit or depression in the surface; the course of these rills curves and meanders in exactly the same way as terrestrial rivers do; and, finally, one end of the rill is at a greater elevation than the other. In the case of these lunar river beds, if such they be, the wide end is higher than the narrow end; and it is supposed that each river originated from geyser springs in a lake, now represented by a pear-shaped depression, and wandered in its bed across the desert country until its water had been exhausted by evaporation. The largest of these formations is 120 miles long, and three miles wide at its point of origin.

By far the most puzzling feature of the surface of the moon consists of certain areas which become extraordinarily bright for a part of the lunar day, but are indistinguishable in respect of brightness from the surrounding areas during the earlier and later portions of the day. That is to say, when the sun's rays fall very obliquely on them, their special quality, whatever it may be, is invisible; but when the sunlight falls on them more vertically, they become not only visible but extremely conspicuous from their brilliancy. Moreover, they can be made out clearly on the "old moon in the new moon's arms", by the vertical rays of earthshine.

The areas of variable brightness with radiating bands of light

These areas of variable brightness, which shine out under a comparatively vertical light, but are obscured under an oblique light, are large, irregular patches including the summits and higher slopes of the crater walls. From these patches of excessive brightness there extend in some cases, about thirty in number, very remarkable systems of rays having the same quality of great brilliancy under a high sun. Thus, from the shining patch around a great crater there may extend in every direction shining filaments or bands of the same character, each band being very narrow, but many of them attaining an extraordinary length, so that in an extreme case a length of 1700 miles has been measured. Some of these systems of bright rays are the most beautiful as well as the most conspicuous objects on the surface of the moon.

It is certain that the bright rays or bands of this kind do not correspond with rills or clefts such as we have already considered. They are remarkably straight, traversing every irregularity of the surface, whereas those cracks in the moon's crust pursue very irregular and often branching courses.

Appearances visible in earthshine that have no earthly analogy

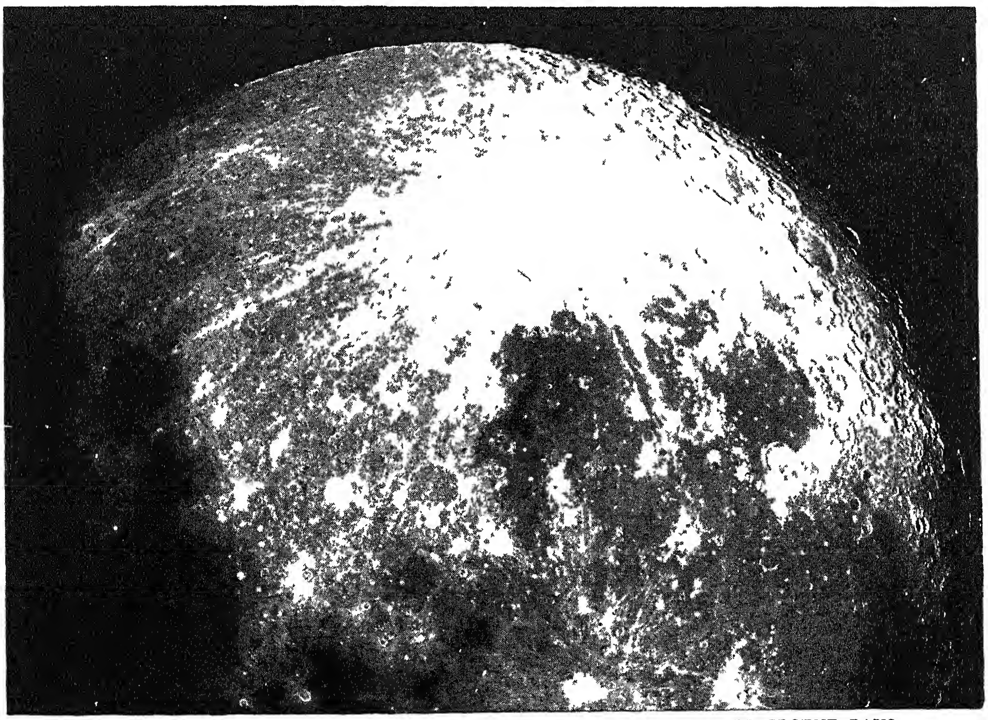
A bright ray has been traced to the edge of a crater, across its floor, up the opposite wall, and then again down the outer slopes of the wall and away across the country. Sometimes the rays of one system cross those of another. without any apparent mutual interference.

The nature of these patches of brightness and of the systems of bright rays which proceed from many of them has been much discussed, with little satisfactory result. There is no doubt that they present a problem for which we have no terrestrial analogy. The fact that they are visible by earthshine proves that their first appearance after the sun has risen upon them for some time is not due to the fact that they are produced by the sun's light or heat. Evidently they are there all the time; only the conditions of their visibility, and not they themselves, are subject to this periodic variation. They are due to some deposit, over certain areas, of materials which shine very brightly when the sun is high, but are invisible when the sun is low.

It is possible that they consist of materials of crystalline texture, the surfaces of the crystals being mainly horizontal. These crystalline materials may have been thrown up in volcanic action, so as to cover the surface of the crater walls; and they may have escaped also from the interior, along immensely long radial cracks in the moon's surface, probably in the form of vapor which has condensed and become deposited along the neighborhood of each of these cracks, so as to constitute the systems of bright rays.

Do the bright patches and bright rays round the craters consist of snow?

It is very difficult, however, to imagine what forces could have produced such immensely long, straight cracks as are postulated in this explanation. But the theory may become fairly tenable if we suppose that the vapors, which were to be deposited as brightly shining crystals, proceeded as fumes from the interior of the craters, and,



THE SOUTH POLAR REGION OF THE MOON, SHOWING THE BRIGHT DIVERGENT RAYS
From a photograph by M P Puiseux, taken at the Paris Observatory.

besides becoming condensed in a crystalline coating over the crater walls and the immediate neighborhood, were guided in radial currents by directing forces of an electrical or magnetic nature, which we can only guess at, but cannot more clearly define. The disposition of the bright rays is of so remarkable a nature as to be unaccountable except by some such influence.

No explanation is here offered; the problem is unsolved, but the solution will most likely lie in the direction indicated.

Though there are no inhabitants of the moon, yet we can transport ourselves in imagination to one of the lunar peaks and consider, as many astronomers have done, what may be the aspect of things as seen on and from the moon. Nor is this a mere idle exercise of our fancy for such an imaginative outlook from the lunar point of view helps us to realize more concretely the differences between the earth and her satellite.

The desert scenery of the moon which no artist can portray

With this purpose, landscapes have often been drawn of portions of the moon's surface, as seen, for instance, from the summit of a crater wall; and the artist has attempted not only to introduce the most characteristic features which can be made out with the telescope, but also to give effect to the absence of water and of an atmosphere. The clouds, hills, valleys, plains and vegetation of earth, including

practically all that can be seen in any landscape, owe all their pictorial character to the effects of water — water rising in evaporation, condensed in the air, falling in rain, running in streams, shaping the hills, excavating the valleys, laying out the plains and clothing the earth with verdure. In those regions of earth where water is deficient, we have desert scenery, but the lunar landscape is more desolate by far than any desert, for desert scenery is the work of wind and wind-blown sand, and the moon has no winds — only an eternal, soundless calm. Further, the landscape of the moon is neither softened nor varied by the atmosphere, which is far too rare for any such effect; every detail, near and far, must strike the eye with the same distinctness, and the whole effect be one of black and white.

Yet more dreadful even than this lonely desolation must be the aspect of the heavens. We cannot say the "sky", because of the sky, as we know it, there can be none. The moon has none of this homely, bright, warm shelter of blue and mist and cloud, no sunset hues, no purple gloom of night; it is exposed throughout its day, as in its night, to the outer darkness of infinity, a blackness swarming with myriads of celestial lights.

An innumerable multitude of stars, too faint to be seen on earth, are visible from the airless moon. Here, as never on earth, the sun is seen unveiled in all its glory. Around the brilliant white mantle of incandescent clouds, which alone we see from earth, inhabitants of the moon would see the flaming chromosphere scintillating with every color, and shooting up from this the far-reaching prominences, also of blending and changing hues, some of them shaping and drifting like clouds, others towering like prodigious flames and jets of molten metal. Around the chromosphere and prominences, again, could be seen the threads and streamers of the corona, and far beyond the corona the vast zodiacal light, streaming from the sun in each direction for a distance of more than sixty times its diameter.

From that surface of the moon which we see, the earth is always visible, clearly marked with clouds, continents, oceans and polar snows. The earth forms a huge luminary, passing through phases, just like those of our moon, from new to full, and then again to new. The earth itself as seen from the moon would appear to have a very definite bluish color and to be four times the diameter of the moon as we see that body from the earth.

A STUDY OF SEA-WAVES

Their Formation, Height, Depth, Force, Destructive Power and the Problem of Coast Defense

RAIN STRONGER THAN THE MIGHTY SEAS

THE sun, the moon and the winds allow the sea little rest; they pull and push its waters up and down, here and there. Sometimes there is merely a heaving sway, sometimes just a ripple, sometimes the long billows come like the ranks of an unconquerable army, sometimes there is surge and foam, but always on a sea of any size there is wave-movement. Waves, as commonly understood, are disturbances of the surface of the sea due mainly to the wind, but, of course, the solar and lunar tides always play their part in the resultant motion. The disturbance consists essentially not of a forward stream, but of a progressive up and down motion of the water. Each particle of water affected by the wave motion rises and falls moving forward and backward and so describing an elliptical orbit in a vertical plane. In a wind wave there is a slight forward advance, but no individual wave travels forward as it appears to do; and if a cork be floated on the water it will be seen to rise and fall, and not to travel forward unless carried forward by a forward movement of the water, apart from and independent of the up and down wave motion. Sea-birds floating on the water also illustrate this up and down motion. The waves, in fact, no more travel along than do the waves of a field of waving grain; in both cases the forward movement is an optical delusion, though in the case of the sea, as we have previously mentioned, the upper layers of water are sometimes swept along the surface by the wind.

The height of a wave depends on the force that produces it, and on the length of time the force is in action. Thus, when a gale blows for several days the waves become bigger and bigger. Thus, also, when a wind blows off the land the waves increase in magnitude with increasing distance from the shore. Further, waves are higher the deeper the water in proportion to its area. Thus in the shallow British seas the waves are never more than 15 or 20 feet high, and in the German Ocean and Mediterranean 13 feet is about the maximum, whereas in the deeper and larger Atlantic they often far exceed that height. Scoresby, voyaging from Liverpool to Boston in 1847, measured waves from 26 to 29½ feet in height, and found that the average height was about 19 feet. On a more stormy return voyage, in the subsequent year, he found that the average wave was about 30 feet, and one wave he measured reached 43 feet. A wave of 33 feet has been reported in the Pacific; and off the Cape of Good Hope Sir James Ross noted one of 39 feet. In the Bay of Biscay, proverbial for its heavy storms, no higher wave than 36 feet is recorded. Some observers have asserted that they have seen waves over 100 feet high, but it is certain that no wind-raised wave ever reached that height, and it is probable that 50 or 60 feet is the maximum height of waves raised by wind in the open sea. The highest waves, it may be noted, occur not during the fiercest storms but are the cumulative result of gales blowing persistently in the same direction.


Standard Oil Co (N J)

An oil tanker, making the run from Corpus Christi, Texas, to New York, takes water in a moderate sea Waves of this height offer no particular hazard to large ships like the one that is shown above

HE MAKETH HIS STORM A CALM, AND SO HE BRINGETH THEM TO THEIR DESIRED HAVEN

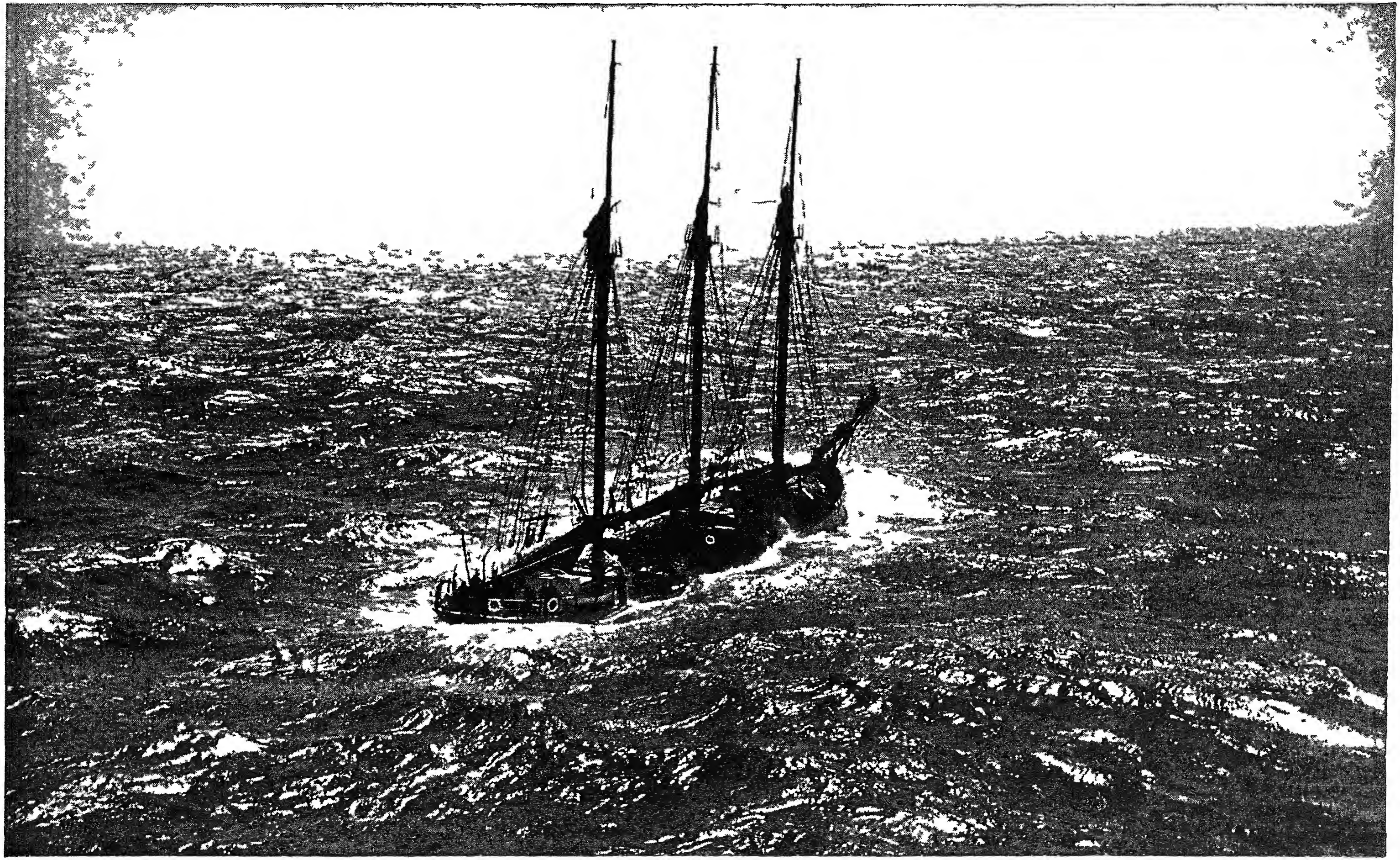


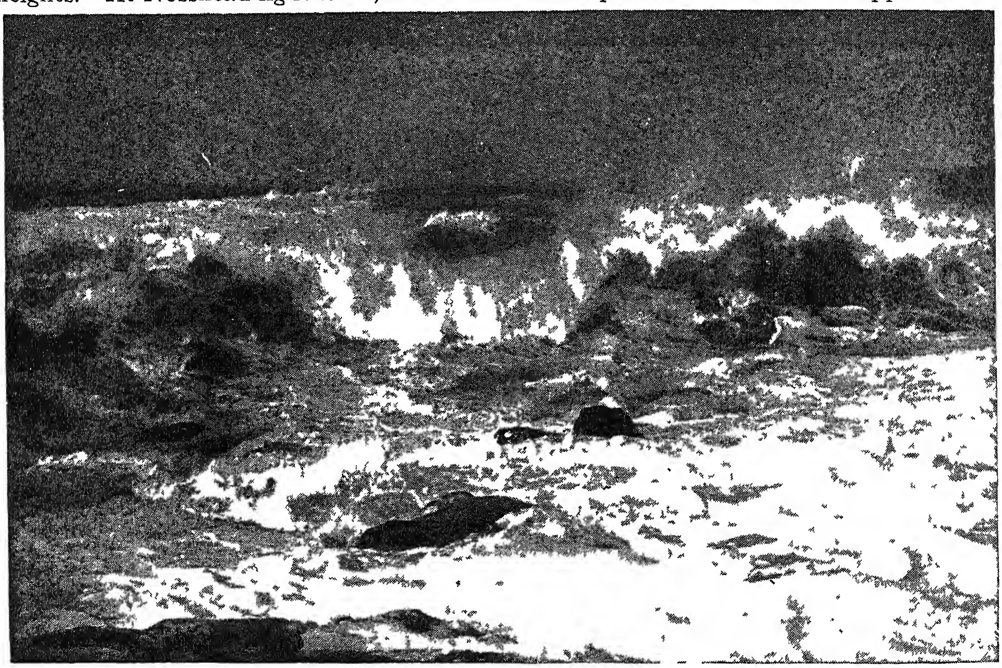
Photo by Burton Holmes from Ewing Galloway

THE SUBSIDING OF THE STORM AS THE GALE DIES AWAY AND THE SPENT WAVES OF MID-OCEAN SINK GRADUALLY TOWARDS REST

Often waves spread out far beyond the actual center of a storm in the form of a long, heaving undulation known as a ground swell, which is most marked where the water becomes shallower, and which eventually terminates in a series of rollers, or breakers, as the friction of the bottom impedes the progress of the deeper part of the swell.

We have said that waves in open sea do not exceed the height of 50 or 60 feet, but the breakers of breaking waves may burst in surf and spray to much greater heights. At Nosshead lighthouse, in Scotland, large volumes of water are thrown up as high as the lantern — that is, to 175 feet above sea level. The Minots Ledge lighthouse, 107 feet high, is often enveloped in spray and foam. The windows of Dunnet Head lighthouse, at a height of upward of 300 feet above sea level, are sometimes broken by stones carried up by the sheets of sea water that break over the building.

So much for the height of waves. Next, we must consider how deep the disturbance goes. Theoretically, it is probable that a wave is propagated downward for a distance 350 times its height. Thus a wave 33 feet in height would reach to a depth of about $1\frac{3}{4}$ miles. This may be true theoretically, but the force of the waves diminishes in geometrical proportion with the depth, and so soon ceases to be appreciable. In some exceptional cases the waves are effective to a depth of 600 feet, for ground-swell has been known to break in hundred-fathom waters "The Atlantic surge on approaching the west coast of Ireland displayed itself in a line of waves on the edge of the hundred-fathom soundings", and the sand on the sea bottom at such depths sometimes bears ripple marks. But, as a rule, waves do very little work at a greater depth than 300 feet, and below 600 feet there is calm during the wildest storm. According to Delesse, engineering operations have shown that submarine structures are little disturbed at depths of 15 feet in the Mediterranean and 25 feet in the Atlantic by ordinary free wave movement.



WAVES BREAKING ON A ROCKBOUND SHORE

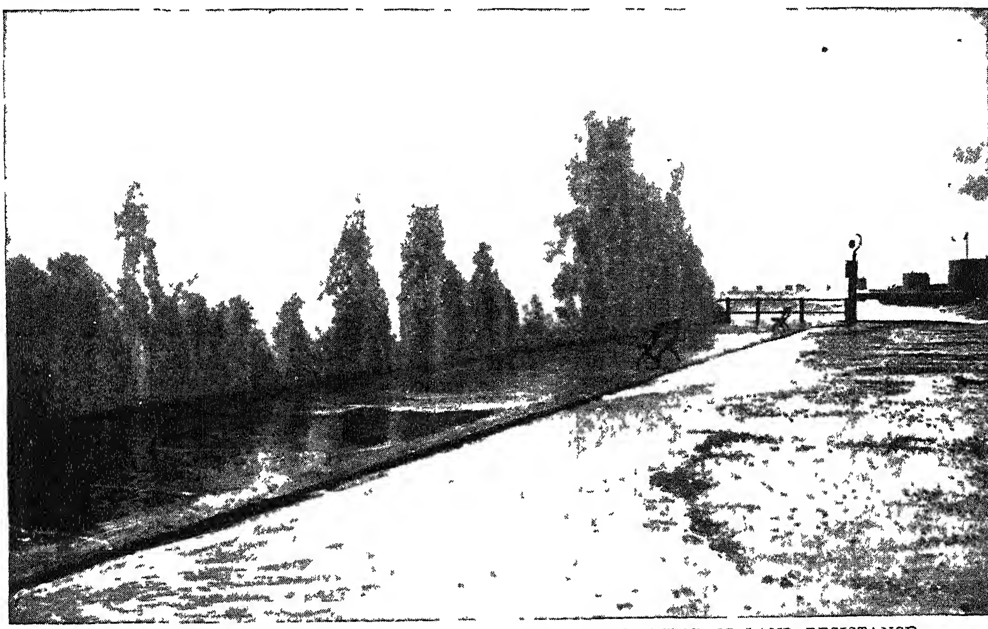
How wide are waves? What do they measure from base to base? On the average a wave is fifteen times as long as it is high. Thus a wave 5 feet high measures on the average 75 feet from trough to trough; and a wave 50 feet high.

750 feet from trough to trough Since some of the huge Atlantic liners are over 900 feet long, it is evident that they can never sink into the trough of the sea.

The velocity of a wave depends partly on its length and partly on the depth of the water. The longer the wave and the deeper the sea, the greater the velocity. Small waves in shoal water travel, as a rule, less than twenty miles an hour, whereas storm-waves in deep seas may go at twice that pace. If we know the length and velocity of a wave, we can calculate the depth of water in which it is traveling; and if we know the width of a wave and the depth of the water, we can calculate the velocity.

The following table, by Airey, shows relative lengths, depths and velocities:

Waves caused by earthquakes are very long and very rapid On December 23, 1854, an earthquake in Japan, at Simoda, started a wave across the Pacific which was recorded in the self-registering tide-gages of San Francisco and San Diego when it reached the California coast. It was calculated from the times of arrival that the earthquake had produced a wave 210 miles in length, which had traveled at the rate of 6 7 miles per minute. Two earthquake waves which were produced in Peru on August 13, 1868, and May 9, 1877, were calculated to have traveled to Japan and New Zealand at about the same rate.

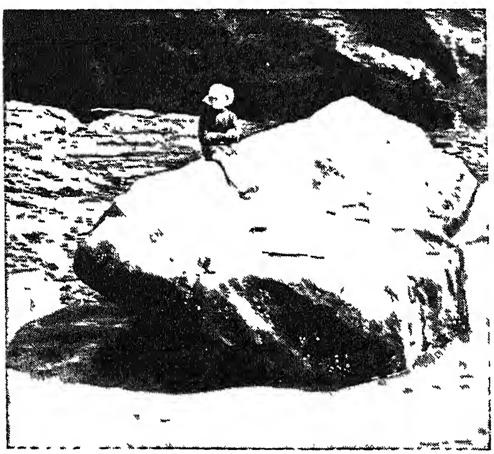


A SILVER BAND OF SPRAY THROWN UP BY WAVE-FORCE MEETING LAND-RESISTANCE

The effect of oil in abating waves has been known for ages. The fishermen in the Persian Gulf tow a pricked bladder of oil to assuage the waves when the sea

Depth of the Water in Feet	Length of the Wave in Feet							
	1	10	100	1,000	10,000	100,000	1,000,000	10,000,000
	Corresponding Velocity of Wave in Feet Per Second							
1	2 262	5.320	5 671	5 671	5.671	5 671	5.671	5.671
10	"	7 145	17.921	17 921	17 933	17 933	17.933	17.933
100	'	"	22 264	53 390	56.672	56 710	56.710	56.710
1,000	"	"	"	71 543	168.830	179 210	179.330	179.330
10,000	"	"	"	"	226.240	533 901	566.720	567.100
100,000	"	"	"	"	"	715.430	1688.300	1793.300

is rough, and similar use of oil is made by the boatmen of Tangier. At Lisbon in rough weather oil is poured on the bar of the Tagus; and Scottish and Norwegian fishermen, when landing through surf, have been wont to squeeze fish-livers to make the oil exude, and then fling the livers ahead of the boat Whalers in the Southern ocean, too, when the sea is rough, are in the habit of hanging large pieces of blubber on each quarter in order to prevent the water from coming aboard. There is no doubt that oil does abate the waves, most probably by preventing their breaking Lieutenant Bechler, U.S.N., who has made a special study of the matter, says: "Oil changes the storm-wave into



WAVE—RESISTING POWER OF ROCKS
This huge boulder at Porthleven, Cornwall, is of gneiss of a type unknown in the rest of Great Britain It has not yet been broken up by the force of the waves, though the slate cliffs are receding inland

the heavy swell. Its specific gravity causes it to float on the surface; it spreads rapidly and forms a film, like an extremely thin rubber blanket, over the water. Its viscosity and lubricant nature are such that the friction of the wind is insufficient to tear the film and send the individual wavelet to the crest; and while the force of the wind may increase the speed of the wave in mass, it is as a heavy swell and not in the shape of a storm-wave. The effect is purely a mechanical change in the shape of the wave, and there is no evidence of any chemical action by the oil on the water."

The force of waves is prodigious. Water is a heavy substance, and when flung in large quantities it acts like a colossal battering-ram. The engineer who built the Eddystone lighthouse calculated that during storms it would be exposed to a pressure of 3013 pounds on the square foot, but at Skerryvore lighthouse, on Tiree, more than twice that pressure has been recorded; and at the Bell Rock lighthouse, at the mouth of the Tay, the tremendous pressure of 6720 pounds has been registered. And even greater force than this has been found in some instances. On several occasions the winter breakers in the North Sea and Atlantic have been found to exert a pressure of nearly 7000 pounds per square foot, and at Dunbar a pressure of about 8000 has been noted.

Force of this magnitude can toss boulders like marbles. At the Tillamook lighthouse in Oregon, one of the most exposed lights in the world, a mass of concrete, weighing over half a ton, was thrown during a storm over the fence into the inclosure at a level of 88 feet above the sea. On any coast, indeed, exposed to heavy seas, blocks of stone or mortar tons in weight may be tossed about. At Barra Head, in the Hebrides, a block of stone weighing forty-three tons was carried nearly two yards by the breakers. During a cyclone in the Azores in 1887, rollers 25 or 30 feet high "came with such force upon the breakwater that vast blocks of stone were tossed about like pebbles, and thick iron stanchions snapped as if they had been bits of stick". The full force of the Atlantic rolling in the Bay of Biscay is sometimes terrific. Blocks of masonry 36 tons in weight have been thrown for 11 or 13 yards; "one block was even raised nearly seven feet, carried over the breakwater, then thrown down, and rolled to a distance during the storm". At St. Jean de Luz it has been necessary to employ masses of stone of not less than 80 or 90 cubic yards.

But still more wonderful instances of the power of the waves may be cited. "In the Isle of Réunion there is to be found in the middle of a savannah a massive piece of madreporic stone, which is no less than 510 cubic yards in size. It is a piece that the waves have detached from a reef and driven before them far across the land."

At Wick Bay, Scotland, during a futile attempt to construct a breakwater, a big block of concrete weighing about a thousand tons was laid and securely fastened at the seaward end, but the very first winter storm hurled the ponderous block away. Strong iron bars eight inches by three were broken as easily as Samson snapped the withes. Finally, to close this tale of prodigies, "at Plymouth a vessel weighing 200 tons was thrown, without being broken, to the very top of the dyke, where it remained erect, as on a shelf, beyond the fury of the waves".

THE SPOILS OF THE SEA — A SUBMERGED FOREST IN MOUNT'S BAY, CORNWALL, ENGLAND

Considering, then, the mighty force and patient persistence of waves, it is little wonder that the coasts of the world are being constantly sculptured and changed by the constant assaults of the sea. And its destructive power is much increased by the fact that it drives compressed air before it like wedges into any crevices in the surfaces that dare to oppose it. The compressed air, again, suddenly expands when the pressure is reduced, and acts almost like an explosive. Further, the waves bombard the coasts with rocks they have already torn from it, and bruise and abrade the land with showers of stones, pebbles, shells and sand. All along the coast, needles, stacks, caves and coves testify to the bombardment of the billows. In many places the sea is rapidly encroaching on the land. In 1862, during a terrible hurricane, the sea eroded away a belt of rock at La Hève more than fifty feet thick, and since the year 1100 this cliff has been eaten away at the rate of more than two yards a year. At Calvados the coast is eroded at the rate of nine or ten inches annually, while on the coast of Seine Inférieur the annual erosion is about a foot. The island of Heligoland, in the North Sea, once a fertile island of considerable extent, has melted away in the sea like a lump of sugar, till now it is little more than a rock. The shores of Hanover, Friesland and Holland were steadily gnawed and nibbled away for sixteen hundred years, and at times there were sudden eruptions of the sea. One eruption in the twelfth century formed the Zuyder Zee, another in the thirteenth century made the gulf of Jahde. In 1230 an inundation of Friesland drowned a hundred thousand men. In 1277 the gulf

of Dollart was made In 1288 the Zuyder Zee overflowed and drowned 80,000 people In 1421 seventy-two villages were submerged And now further encroachments of the sea are prevented only by dikes and sea works

At Long Branch on the Jersey coast, the advance of the sea, in spite of elaborate breakwaters, has been so rapid in recent years as to menace important buildings while a few miles to the north and south the land is advancing in the face of the waves The encroachment, then, of the sea on the land is not universal or uninterrupted

On the south side of Nantucket Island the sea cliff has retreated as much as six feet in a single year, and on the English coast the sites of villages have disappeared in the waves during historic times

Professor Le Conte gives the following description of the action of the waves in changing the American coast "The coasts of the United States show many examples of the erosive action of waves and tides The form of the whole New England coast is largely determined by this cause The softer parts are worn away into harbors by the waves and scoured out by the tides, while the harder parts reach out like rocky arms far into the sea Sometimes only small rocky islands, stripped of every vestige of earth, mark the position of the former coast-line Boston Harbor and the rocky points and islands in its vicinity are good examples The process is still going on and its progress may be marked from year to year On the Southern coast examples of a similar process are not wanting At Cape May, for instance, the coast is wearing away at a rate of about nine feet per annum The more exposed portions about Charleston Harbor, such as Sullivan's Island, are said to be wearing away even more rapidly As a general fact, however, the low, sandy or muddy shores of the Southern coasts are receiving accessions more rapidly than they are wearing, while, on the contrary, the New England coast, as proved by its rocky character, is losing much more than it gains The shores of Lake Superior furnish many beautiful examples of the action of waves — in this case, of course unassisted by tides The general form of the lake along the south shore is determined by the varying hardness of the rock, the two projecting promontories La Pointe and Keweenaw Point being composed of hard, igneous rocks, while the intervening bays are softer sandstone On the south shore, between La Pointe and Fond du Lac the conditions of rapid erosion are beautifully seen The shores are sandstone cliffs with nearly horizontal strata These have been eroded beneath by the waves, in some places for hundreds of feet, forming immense overhanging table-rocks, supported by huge sandstone pillars of every conceivable shape Among these huge pillars, and along these low arches and gloomy corridors, the waves dash with a sound like thunder From time to time these overhanging table-rocks, with their load of earth and primeval forests, fall into the lake" Erosion by the waves has reduced the area of Sharp's Island in Chesapeake Bay from 438 acres to 53 acres in 62 years The lighthouse at Cape Charles, Virginia, which was erected in 1827, was located 700 feet from the shore It was abandoned after 36 years owing to the encroachments of the sea and the whole site has been washed away The second lighthouse, also 700 feet from shore, stood on the edge of the water after a somewhat longer time It was deemed advisable to erect the third lighthouse about 3600 feet further inland

There is something very dramatic about the fight between the land and the sea — about the fight between man and the waves for the possession of the foreshore, but it is really not such an important fight as it sometimes appears When we hear that thousands of acres have been washed into the sea we are apt to imagine that the rest will soon follow But, as a matter of fact the sea as a rule nibbles away at the land very slowly and ineffectually "Before the sea," says Geikie, "advancing at the rate of ten feet in a century, could pare off more than a mere marginal strip of land between seventy and eighty miles in breadth, the whole land might be washed into the ocean by atmospheric denudation"

THE BIG STEPS OF CHANGE

How Two Botanists — a Dutchman and a Dane — Have Added to our Knowledge of Life's Broadening Growths

AN AMSTERDAM THEORY OF MUTATIONS

THE science of heredity is still young, and, as is usual with young sciences, still requires to be discussed along various lines, each associated with the name of some special student and pioneer. Gradually we are learning how these various views and methods are to be employed for a completer science, which can proceed confidently from first principles to details. In our present attempt to make a fresh review and judgment of the most rapidly changing and developing part of all science — excepting radioactivity — we have successively dealt in logical, though not in chronological, order with the work of Galton, Weismann and Mendel. We now come to that of the botanist, Professor Hugo De Vries, of Amsterdam, whose great book, "The Mutations Theory", was published in 1901, the year after the rediscovery of Mendel's forgotten work of a generation before. It has played a leading part in the development of our knowledge during the last two decades, and there is little doubt that the friendly rivalry and cooperation of the Mutationists and the Mendelians, is the chief hope of the science of genetics for many years to come.

Two years after the publication of "*Die Mutationstheorie*" there appeared a very important paper by another botanist, Professor Wilhelm Johannsen, of Copenhagen, which modified, confirmed and extended the work of De Vries. Any serious study of heredity today demands acquaintance with the experiments and discoveries of these two distinguished men, and we have only to define the mutations theory in order to see that, if it be well founded, it marks a conception of heredity, and therefore of evolution, fundamentally distinct from that which is set forth in "orthodox Darwinism".

De Vries introduced the term "mutation" to express his conception of the origin of species, or of a new specific character, when this occurs by the taking of a single new step. He believes that these new steps, which may be of very great size, are by no means very common or general, and that *in them alone is the true origin of species.*

At once we see that this is a theory which is directly and notably opposed to Darwin's. His theory was that organic evolution was by the natural selection of minute variations, which were incessantly occurring in all directions, from generation to generation of all living creatures. Darwin could have made a better case for organic evolution, apart from any special theory, if he had laid stress upon the appearance of large, striking variations of the kind commonly called "sports", and to which De Vries gave the scientific name of "mutations". But it was not Darwin's way to use evidence for his case in which he did not himself believe. It seemed to him that "sports", though they looked at first like the obvious origin of new species, did not withstand close inspection; they were, above all, inadequate to account for the adaptation of species to their environment, and there were many other criticisms of their apparent claim to furnish the origin of species, according to the knowledge available to Darwin.

The confirmation by De Vries of Huxley's belief that nature makes jumps

Professor Huxley, Darwin's great champion, was wise in his generation in this respect, as the following very interesting passage shows: "Mr. Darwin's position might, we think, have been even stronger than it is if he had not embarrassed himself with the aphorism '*Natura non facit saltum*', which turns up so often in his pages. We believe . . . that nature does make jumps now and then, and a recognition of the fact is of no small importance in disposing of many minor objections to the doctrine of transmutation." The argument of De Vries and his school today is that Huxley here was right, and would have been quite justified had his criticism been far stronger. Nature does sometimes make leaps, or "saltations", as they are sometimes called, and these leaps or jumps are none other than the "mutations" of De Vries, in which, as against the minute variations accredited by Darwin, he and his school believe the origin of species to occur.

As we have already briefly explained, the work of De Vries and the modern experimental school in general has shown us that there was a most fundamental error at the root of the Darwinian theory of organic evolution. Darwin assumed that the minute random variations he discussed were inheritable. Today we are taught, by work done since Darwin's death, that the differences which occur between offspring and parents are of several different kinds, having different consequences, and must be distinguished accordingly.

The mutation theory of De Vries forecast in the seventeenth century

It is, above all, to De Vries that we owe the new view that the "sports" rejected by Darwin and the early builders may be something like the headstone of the corner. Not that this new view is an exception — though there are exceptions, or there would be no evolution — to Solomon's dictum about new things in general. In point of fact, the theory of evolution arising in sports or mutations is fairly definitely hinted at in Aristotle; and Professor Punnett has noted a passage in the writings of Sir Thomas Browne, the famous author of the "*Religio Medici*", in which that remarkable man definitely states the mutations theory in all essentials to explain the various colorings of men and foxes, lions, crows, etc., and actually concludes: "All which mutations, however they began, depend upon durable foundations, and such as may continue forever."

That is the modern "mutations theory" of De Vries in one powerful sentence, published in the year 1650 — the theory that the characteristics of species arise in mutations, which "depend upon durable foundations", *in the germ-cells*, "and such as may continue forever", because of the nature of the germ-plasm, its "continuity", and "immortality", as Weismann has since taught us to say. And with that remarkable definition and anticipation of Sir Thomas Browne is involved the discarding, as aids to evolution, of all variations which *do not depend* upon durable foundations, because they are not built upon the germ-plasm, are not rooted in that, but are merely the accidental results of the interplay between the individual body and its environment.

The difference between mutation and fluctuation a vital point

Some years before De Vries published his book, the English student, Professor Bateson, in his "Materials for the Study of Variation", had shown that there exists a profound and all-important difference between those variations which do not depend upon the durable foundations of the germ-cells and those which do. Today, we are compelled, above all by the special studies of De Vries and of Johannsen, soon to be described, to acknowledge that distinction. And we must speak, in the language of De Vries, of the merely nutritive or environmentally produced difference as a fluctuation, and of the germinal difference as a mutation. And here we must beware of a very common error, not inexcusable, into which many have fallen.

The difference between a mutation and a fluctuation is one of nature, not of size.

The point is not, as so many have supposed, that whereas a fluctuation is a minute and scarcely measurable variation from the type of the species, a mutation is something large, extraordinary, obvious. A fluctuation may be very large and obvious, and a mutation may be very minute and subtle. If we consider cases of morbid nutrition, including, for instance, such a disease as rickets, we see that a mere fluctuation, according to the biological definition, may yet show itself in such a striking form as aggravated knock-knees. No mutation of the bony characters of the human body would be likely to approach in intensity such an abnormal condition of the bones of the leg. But that condition is nutritive, not founded upon the sure ground of the germ cells, and it is to be ignored from the standpoint of heredity.

How the experiments of De Vries showed the limits of selection

On the other hand, a true mutation is by no means necessarily anything so notable and largely novel as, for instance, the sudden appearance of a nectarine upon a peach tree. On the contrary, even the tiny but definite differences which modern Mendelism studies, and many of which are quite as minute as mere "fluctuations", may yet, if only they be dependent upon differences in the composition of the germ cells, furnish the origin of new forms that will persist.

Having these principles and definitions clearly in mind, we may proceed to the precise contributions of De Vries to our subject. In the first place, he carried out a number of experiments in which he tried to modify the characters of certain plants by means of simple, straightforward selection along Darwinian lines. He found that selection made a difference at first, but that thereafter, no matter how stringently and accurately he selected for certain characters, nor how many generations he practised upon in succession, all that he could do was to maintain the characters obtained very early in his experiment. Here, indeed, begins the crucial experimentation which shows how sharply set are the limits of selection.

The illustration of the Shirley poppies — a new type suddenly evolved

The argument of De Vries and the Mutationists, therefore, is that there must be something else, other than ordinary fluctuation, which is really effective in changing species. This something else is the process he calls mutation, and the products of it may be called "mutants" — the changing things. Let us see what actually may happen — and let us hope some day to discover how and why it happens.

The Shirley poppies are a celebrated illustration, which may be cited in the words of Mr. R. H. Lock, a prominent botanical student of heredity. He writes as follows: "Of the origin of a new type of plant in this definite and sudden fashion, the Shirley poppies furnish an excellent example. These originated in a mutation of the common wild field poppy. In 1880 the Rev. W. Wilks, Vicar of Shirley, near Croydon, noticed among a patch of this plant growing in a waste corner of his garden a solitary flower, the petals of which showed a very narrow border of white. The seeds which this flower produced were sown, and next year, out of about two hundred plants, there were four or five upon which all the flowers showed the same modification. From these, by further horticultural processes, the strain of Shirley poppies originated. We may point out in passing that if the original plant had been self-pollinated, a much larger proportion of the new type might have been expected to appear in the next generation."

The theory that new breeds arise from definite novelties

For De Vries and the modern school of biologists, such an instance of what actually happens is invaluable and all-significant. In his judgment all new domestic breeds have arisen by the "discontinuous" method as definite novelties; and this which we know, and which Darwin, of course, well knew, to be so generally the case for the origin of new domesticated forms of animals and plants, is in the belief of the mutationist school true also of the origin of natural species as well.

There is the essential difference between the Darwinian theory and the mutationist theory. And since the latter lays no stress worth mentioning upon the process of selection, which was essential in Darwin's theory, we now often speak of the opposing camps as respectively selectionist and mutationist. For, as Mr. Lock puts it: "If new types are not produced among domesticated productions by the action of artificial selection, and all that selection can effect is to pick out definite novelties when they occur, the analogy between natural selection and artificial selection breaks down, and a large and important section of the evidence in favor of the production of natural species by the action of natural selection is destroyed. In the place of this explanation De Vries would put the theory of mutation, according to which new species arise by single steps as definite novelties, just in the same way as we find that domestic varieties are produced. More than this, De Vries believes that he has discovered a set of new species in the very act of originating from an old one in this way, a discovery which affords the basis and groundwork of the views which he puts forward."

The timely illustration found by De Vries in the evening primrose

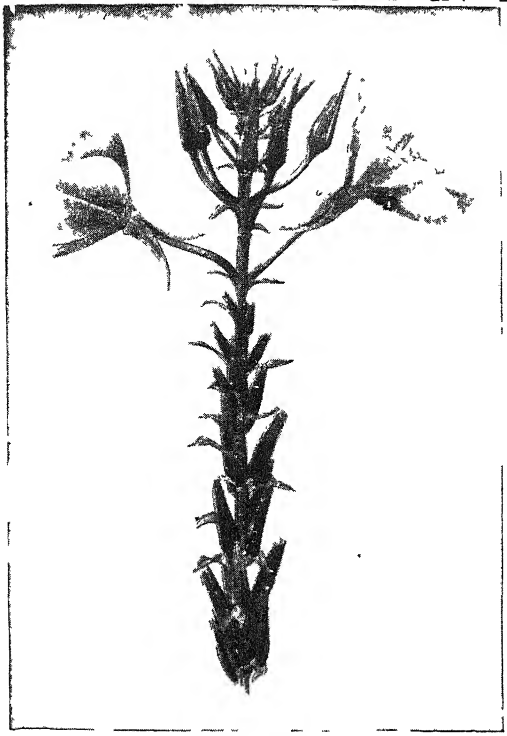
And so we come to this celebrated observation of De Vries upon the species of evening primrose, a native of America, which is known as *Œnothera lamarckiana.* There is something right and apt in the name of this species, carrying us back to the great pioneer of evolution who declared that altered external conditions may sometimes originate real transmissible changes in the germinal characters of living things. Certain specimens of this plant escaped from a garden in Holland, and De Vries found among the "escapes", or their offspring, two distinct new forms, each unlike all the rest. Each occurred in a separate patch, as if a single plant had borne all the new individuals in each case.

De Vries made full use of his remarkable opportunity, and the first fact which he discovered was that the seeds of these plants, when sown in his garden, produced offspring like the parents. In a word, two new species had actually been observed and proved to arise from an old one in a state of nature. Following on this, De Vries set to work to study more closely the cultivated offspring in his garden of the various types of evening primroses which were first observed running wild as garden escapes, and after very wide and detailed experiment he showed that out of fifty thousand individuals grown so that they could be defined and identified, more than eight hundred, or one and a half per cent, were novel, differed from *Œnothera lamarckiana* and could only be called mutations.

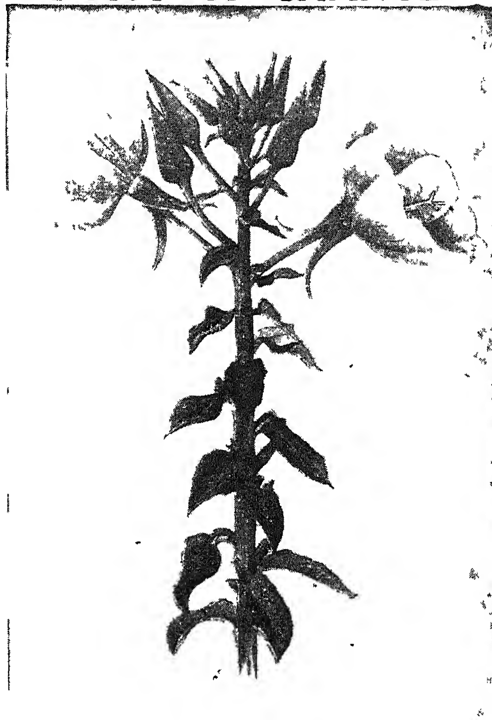
The theory that a period of mutation occurs once in four thousand years

It looks as if De Vries had had the great good fortune to chance upon a species just when it was breaking up into a number of new species. Until this famous research of his it had never been supposed possible to make observations directly upon the origin of new species *under natural conditions* But De Vries showed that it was possible to do so; and the results which he obtained were, as we have seen, of a most remarkable and unexpected kind Perhaps the actual work of De Vries in his experiments was better than his interpretation of it. We need not here trouble ourselves at length with his various theories as to the causes which lead species to break up, nor as to the correspondence between the known characters of species and certain assertions of the geologists. De Vries is as prolific a speculator as an experimenter. He supposes that something like four thousand unit characters, each of which has arisen by a single mutation in the past, would account for the constitution of the highest form of life we know — ourselves — and that a period of mutation recurs about once in every four thousand years. So he concludes that a period of sixteen million years would suffice for the gradual unfolding of the body of man from the lowest forms of life at a rate of one mutation every four thousand years. All this is highly fantastic, but it may be recorded for its significant contrast with the solid qualities of his work, when he confined himself strictly to observation.

PLANTS CAUGHT IN THE ACT OF CHANGE



ŒNOTHERA LAMARCKIANA



ŒNOTHERA GIGAS

ŒNOTHERA ALBIDA

ŒNOTHERA OBLONGA

ŒNOTHERA SCINTILLANS

How new species come into being is one of the most important problems in biology Professor Hugo De Vries happened to catch the evening primrose, *Œnothera lamarckiana*, when it was mutating, and on this page are pictured with it four of the fifteen new species which he grew from it Of these fifteen, *Œ gigas* was the strongest and finest, and appeared only three times *Œ albida* was noteworthy because, at a very early stage of the seedling, its novelty was apparent; it was a small and pale species *Œ oblonga* had narrow leaves with long stalks *Œ scintillans* was the rarest form of the mutants and proved an inconstant species, tending to give rise to other species. These pictures are reproduced by permission from " The Mutation Theory", by Professor De Vries.

An American vindication of some of De Vries s contentions

Whatever may be said of his speculations, the facts which De Vries described were in themselves startling enough, and botanists could not accept them, it need hardly be said, without confirmation. That was ere long afforded by the experimental school of American botanists, who have such splendid opportunities provided for them by the wealthy men of this country — above all, by the Carnegie Foundation. At the New York Botanical Gardens, Professor Macdougal was able to show that what De Vries observed in the case of the seeds of the *Œnothera lamarckiana*, as found in Holland, was undoubtedly as he had described it. Indeed, Macdougal, somewhat improving upon De Vries's methods, found mutation to be occurring in about three per cent, rather than one and a half per cent, of the total number of seedlings grown from seeds sent across to him from Holland. And close observation, in the hope of finding other species which were undergoing mutation, in the fashion of *Œnothera lamarckiana*, was rewarded in some instances

Mutation must therefore be accepted as a fact, and the question of its interpretation becomes a pressing one, especially since so much has been claimed for it by De Vries himself. He naturally set to work to see whether similar phenomena to those of his evening primrose could be observed in the case of other species available to him. He grew and examined large numbers of the seedlings of a great proportion of the plants in his district, but found no sign of mutation in any of them. Hence he concluded that species have long lives of stability, rarely but notably chequered for relatively short periods by a sudden and sharply contrasted tendency to mutation, and he argued that the evening primrose he studied first happened to be in one of these rarely recurring stages of mutation, while the other species were not. As we have seen, he even ventured to name periods of years to correspond to the rhythm he imagined between stability and mutability.

No real evidence of any kind exists in favor of this view.

The want of evidence of any rhythm between stability and mutability

Mutation has its causes, of course, and when they are at work mutation is the result. In their absence a species remains stable. And we shall see that Macdougal and others are beginning to show how the application of certain factors from without may at any time start mutation, or something very like it, in a number of species already experimented upon.

Having said so much of the "mutations theory" of De Vries, the Dutchman, as published in 1901, we must now proceed to look at the remarkable work done by Professor Johannsen, the Dane and published in 1903. That work has since been confirmed in other quarters, and is now part of the acknowledged achievements of biology in our century. In the title of his paper Johannsen introduced the term "pure line". He studied plants which could fertilize themselves, and he gave the name of "pure line" to all the individuals thus descended from a single individual.

Johannsen's novel achievements and his proof of the theory of pure lines

Hi first experiments were carried out with barley and kidney beans, and the case of the beans will serve our present purpose. Johannsen studied the weight of the beans, and made a remarkable discovery. When he weighed a number of beans that were simply a random sample, he found that they had a mean or average weight around which they varied. The curve of such "continuous variability" can be plotted on a diagram, and is the basis for the mathematical study of variation.

But living creatures cannot thus be reduced to paper; they must be studied at first hand. Johannsen's random sample of beans was really a "population" consisting of the offspring of nineteen parents; and when this population was analyzed separately, Johannsen found that the nineteen pure lines of which it was composed were all distinct. Each of these pure lines had its own characteristic average size of seed and characteristic degree of variation around the average.

If, now we select persistently the biggest of the seeds, or the smallest of the seeds, *within any one pure line*, expecting steadily to increase or decrease the size of the seeds in successive generations in consequence, we find that nothing of the sort happens. The differences in the weight or dimensions of the seeds, within any given pure line, are not inherited; the offspring of the lightest seeds, within the pure line, are as heavy as the offspring of the heaviest. And, further, the reasonable but paradoxical result is obtained that the offspring of small seeds will be heavier than those of larger ones, if the small seeds are small specimens of a pure line whose average weight is high, while the large seeds are merely large specimens of a pure line whose average weight is lower.

Now let us consider what selection, "artificial" or "natural", would accomplish in such cases as this. Plainly, we may practise as rigorous selection as we please within a pure line, and the result will be exactly *nil*. All the individuals in such a line are fundamentally, germinally identical. The differences between them are nutritive, accidental, secondary — personal, not racial. It follows that we shall get seeds of the same average weight, no matter whether we breed from the largest or the smallest specimens, within that pure line. In such conditions selection is impotent.

Suppose, now, that we practised our selection upon a "population" in Johannsen's sense, which was really a mixture of pure lines. The result would simply be that, if we were selecting for heavy beans, we should ultimately isolate the pure line which was characterized by the highest average weight of bean among its members. After that we might continue our selection for as many generations as we pleased, but the weight of our beans would remain constant, because we were merely selecting within a pure line, and the selection of the heaviest beans within that line would produce no heavier offspring than the selection of the lightest. Something more than selection, something constructive, creative, would be required for any further advance. This is the something that Darwin forgot.

The theory of the pure line applies, as has been now proved, to many characteristics besides size or weight of beans. But obviously its significance and working out must become very complicated directly we study a population of living creatures where self-fertilization does not occur. For then the pure lines will very frequently be crossed and confounded by the process of bisexual reproduction, and the tracing of them would soon be impossible. But though we may be unable to trace them, yet, if they really exist, we shall see at once how inadequate is the Darwinian assumption that the selection of variations will produce indefinitely extensive results in the case of any living species. In the particular case just cited, we see how limited is the power of selection, and how the personally small individuals of a large race will have large offspring, and the personally large individuals of a small race will have small offspring; so that natural selection or artificial selection, steadily choosing individuals without discriminating between those characteristics which are accidental and personal to them and those which are in their race, though perhaps not displayed at all in their persons, would find itself constantly fooled.

The relation between Bateson's work and that of De Vries and Johannsen

Briefly, then, De Vries and Johannsen unite to assure us, as the result of their studies in the field of botany, that the distinction between mutations and mere fluctuations is all-important. Not that the distinction had been entirely ignored by others. On the contrary, it must be stated, in justice, that Professor Bateson whose name we specially associate with the establishment and development of Mendelism in our century, had long studied this subject before the nineteenth century closed, and had sought to distinguish between two kinds of variation, which he called respectively "continuous" and "discontinuous". He applied the term continuous variation to the fine gradations observed in the weight of beans, or the height of men, or what you will, when large numbers of them are examined statistically.

This, we now know, is the kind of variation which has been studied by the biometricians for its bearing upon heredity, and which has no bearing upon heredity. Bateson further insisted upon the existence of discontinuous variations, which arose as definite, unmistakably different characters, not just fluctuating on one side or another and a mean, like the marks on a target. These were marks *of a different kind.* It is now, of course, obvious that the "continuous variations" of Bateson are the "fluctuations" of De Vries, and that "discontinuous variations" are the "mutations" of the latter's terminology.

The gist of Johannsen's observations that mutations and fluctuations differ

Strong suspicions at once arise that these two phenomena are different not merely, or even necessarily, in measure or quantity, but in kind; that, in the extraordinarily exact words in which Sir Thomas Browne anticipated our new theory by two and a half centuries, "Mutations, however they began, depend upon durable foundations, and such as continue forever", whereas fluctuations or continuous variations, mere oscillations around the mean of their type or line, have no durable foundations in the germ-cells, are therefore not inherited, and are therefore worthless as foundations for any theory of evolution. But it was upon these that Darwinism was founded.

Johannsen's contention that there is no variation in pure lines

And, lastly, as we have seen, the work of Johannsen upon pure lines has begun to provide us with a most admirable and instructive criterion of this difference, now seen to be all-important, between the variations that matter and the variations that do not. The question is still the subject of necessary experimentation, and will long be so, but Johannsen has definitely taught us that for certain characters of certain plants, at any rate, the difference between fluctuations and mutations, between continuous and discontinuous variation, between mere oscillations and the vital jumps, which Darwin rejected, is real and cardinal *when tested by selection.*

The relation between the theory of jumps and natural selection

For experiment shows that selection of mutations alters a race, so long as further *mutational* material for selection remains, but that selection of mere fluctuations effects nothing. How Darwin would have loved to learn the manner and degree in which his own knowledge has been superseded! And how the Darwinians are distressed!

Yet let us beware of rashly supposing that "natural selection" may henceforth be ignored. Certainly none of the leaders of the new developments could be quoted as of that opinion, and several of them have definitely spoken far otherwise. If conditions are suitable — that is to say, if there be overproduction and a struggle for life — natural selection must obtain, and the best adapted must survive. Only we now realize, more clearly than ever before, that they may owe their survival to characters which are germinal and racial, or to characters which are merely personal to themselves. That matters nothing to them, but it matters everything for the consequences of the selective process. For if selection selects mutations, the race will change accordingly; if it merely selects fluctuations, the race will not be affected at all — as in the crucial experiments of Johannsen. Now, there is every reason to suppose that, in the overwhelming majority of cases, the differences upon which natural selection has any opportunity to act are mere fluctuations, and that mutations, which alone matter for evolution and the origin of species, are relatively very rare. By so much is the potency of natural selection *for the future* reduced, though it retains its power to determine who shall be the survivors and who the rejected in any given generation. That may be a relatively humble function for natural selection to discharge, but it is by no means to be neglected. For, even so, natural selection contributes substantially to the problem of adaptation, which Darwin was seeking to solve, simply by choosing, in each generation in turn, those candidates whose personal adaptation happens

H. De Vries, who introduced the term "mutation."

to be most complete. Their advantages may rank merely as fluctuations, may therefore be nontransmissible, and matter nothing for evolution, but they nevertheless serve in some degree to explain the adaptation existing in the world of life at any given moment — in any given generation.

In summary, it should be repeated that though De Vries acutely observed the supposed mutations of the evening primrose, he was wrong in saying that a mutation is only a large and perfectly distinct hereditary change. Mutations of every conceivable extent occur. The mutant character, whatever its extent, is a definite change in an organism's hereditary constitution. It arises suddenly, or spontaneously, and it breeds true from the beginning, giving rise to a new and distinct variety. The mutation process is the source of hereditary variability and is the mainspring of evolution, for it supplies the raw material upon which natural selection operates.

To say that a natural phenomenon such as mutation arises spontaneously is, of course, to admit ignorance of the real causes of mutation. Recent experimental work definitely shows that mutations can be induced by radiation — X rays, gamma rays, ultraviolet rays and neutron bombardment — as well as by extreme temperature fluctuations and by chemical agents. But it seems justifiable to say that such treatments for effecting mutations merely speed up the spontaneous mutation process exhibited in nature, rather than induce new kinds of changes. Thus the origin of mutations still remains unsolved. Some geneticists suspect that many mutations arise ultimately from intra-atomic disturbances in the hereditary material. Whatever the causes of mutation, we are quite aware that the subject matter of this scientific investigation involves the very nature of life. Men like Galton, Weismann, Mendel, De Vries, Johannsen and Bateson have paved the way most brilliantly; but further investigation is much to be desired.

Both photos, Brown Brothers

Wilhelm Johannsen, the Danish geneticist.

A PLANT THAT BREAKS ALL THE RULES

Pan American Airways

Orchid grown near Medellín, Colombia. The orchid is a rarity among plants. It grows upon trees without obtaining nourishment from them; it derives its moisture from the air by means of aerial roots.

INTELLIGENCE IN PLANTS

Movements of Roots, Leaves and Other Organs; Sensitive Plants, and Response to Sunlight

PLANTS THAT CATCH AND EAT INSECTS

WE are accustomed to associate the idea of intelligence with such animals as have a somewhat highly developed brain, but it is an extremely difficult matter to lay down any line of distinction to indicate where intelligence first makes its appearance. If we consider the idea of intelligence in the widest sense, understanding that term as meaning purposeful action, the doing of something for a particular end in view, we should all be ready to admit that many of the processes going on in the leaves of plants might be described as intelligent.

It was in that sense that Darwin compared the tip of the root to the brain of the lower animals. He said it was hardly an exaggeration to say that the tip of the root, thus endowed, "having the power of directing the movements of the adjoining parts, acts like the brain of one of the lower animals, the brain being seated within the anterior end of the body, receiving impressions from the sense-organs, and directing the several movements".

In this sense, plants have well-defined intelligence, which manifests itself in a thousand ways, particularly in the movements which their various parts display, either in search of food or for some other vital purpose. In this chapter we shall study in detail some of the more striking of these movements.

We may first notice the fact that the growth of a plant is not equal in all of its parts. Some portions exhibit a much more rapid growth than others, or grow during a longer period of time; and one of the results of this inequality of growth in different tissues is to produce movements in the various parts which are sometimes described as spontaneous. In both stems and roots the growth is usually more rapid on one side than on the other, and this results in the production of curvatures, or bends, unless the variation is such that the extra growth produced on one side is at once compensated for by a corresponding growth on the other. That is what actually happens at the tip of the root, and it has the result of making the root describe a spiral course through the soil, instead of a directly downward one. As a matter of fact, many stems in their upward growth also have a similar spiral movement, commonly in the opposite direction to the hands of a watch. The movement itself is termed "nutation".

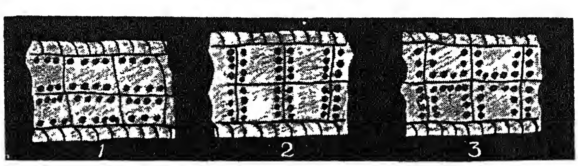
If these spontaneous movements, of roots especially, be carefully studied, the observer cannot help being impressed with the idea that they have a very definite object in view. Hence the justification for the use of the expression "the intelligence of plants". Obviously, the end and object of the movements is to attain that position in the soil which is best suited for the furnishing of the nourishment required. This is seen even in parasitic growths, which direct their growing tips toward the axis of the branch on which they are growing, just as an ordinary plant directs its main root, in the first place, toward the center of the earth, even though it may adopt a spiral course to attain that direction. Seeds which lie under water sometimes send roots directly upward. In all these cases the primary direction of the root-growth — the movement of the root-tip, that is — is extremely definite.

The directions taken by the secondary roots, however, from whichever part of the plant they may arise, are not so definitely circumscribed, though here, too, it is obvious that the movements are directed to reaching such positions as will give either security of attachment or moisture for nourishment. Study of all these movements shows that both those which take place in the aerial structures and those which take place in the root, follow the same guiding principle, though the latter, of course, are made much more restricted from the nature of their environment. If the root were to grow straight down, it would not come in contact with nearly so much material as it does by following a spiral course. This latter evidently offers the best and surest means of encountering the most desirable food-supplies. This is part of what is meant when we speak of the "intelligence" of plants.

SPIRAL ROOT OF EUPHRASIA

Further, one may readily observe that the growing portions of roots may turn aside from dry or barren soils in favor of a part in which there is more moisture and more nourishment. In some plants growing where there is excessive moisture the direction may be toward the drier regions. This reaction of an organism or part of an organism toward or away from water is called hydrotropism. While the roots of most plants may show positive hydrotropism and grow toward water, their stem will probably show negative hydrotropism and grow away from it. In any considerable section of soil which has much vegetation growing at its surface, these movements of roots, in response to their environment, form an obvious and interesting study. One can see in any such cutting of ground a root turning away from dry, sandy or inhospitable soil, until it comes to a richer deposit; and here, not having any necessity to turn further, it will now grow straight downward through good material. Arrived at the further boundary of this deposit, it will once more change its direction, and may even bend round and round, so as to keep in such a desirable neighborhood.

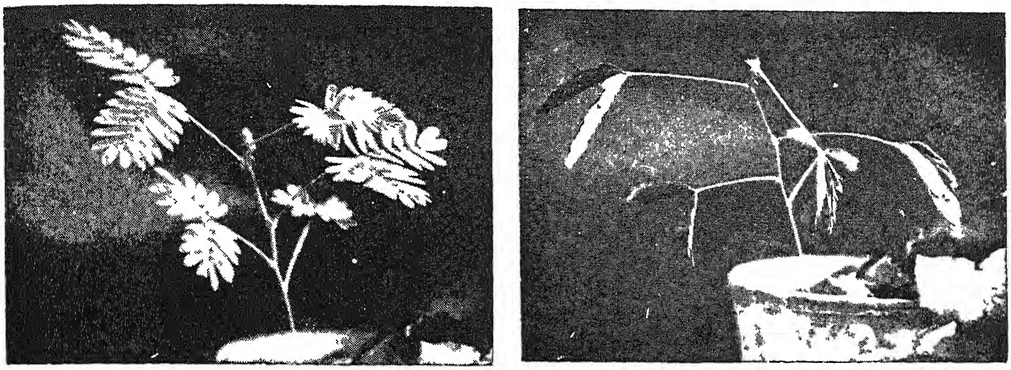
Perhaps one of the most interesting of all the many examples of the intelligence of plants, in reference to the movements of their parts, is to be found in connection with the attitude and arrangements of their chlorophyll granules in relation to sunlight. These granules, it must be remembered, float freely within the protoplasm, which can move them to different places. This permits of their being either equally distributed throughout the cell, or aggregated together in clumps, or otherwise arranged. Perhaps the best example of these movements can be seen in plants like the liverworts, or in the mosses, where the green of the leaf is noticed to be lighter or darker according to the intensity of the light which falls upon it. The same thing takes place in many flowering plants The darker tint is observed when the light is weakest, whereas, under the action of the most intense, direct sunlight, the leaf appears yellowish. These alterations in color appearance may be due to actual movements of the chlorophyll granules, which take up different positions as the light varies.



THE MOVEMENT OF CHLOROPHYLL GRANULES IN A LEAF

This diagram of part of a section of a green leaf represents roughly the change in the movements of the chlorophyll granules in response to the stimulus of (1) darkness, (2) direct sunlight and (3) diffused light

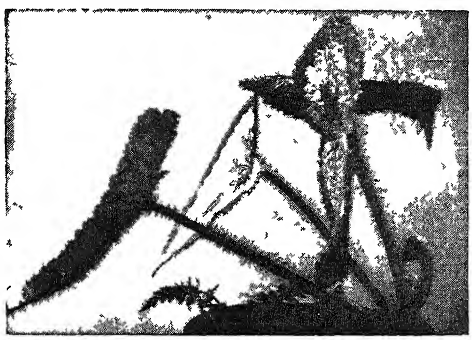
A very simple experiment may be performed by anyone in this connection. If a piece of black paper be taken and placed on a leaf which is exposed to the sun in such a way as to cover up a part of the leaf, after a time it is observed, on removing the strip of paper, that the portion of



A SFNSITIVE PLANT, MIMOSA PUDICA, BEFORE AND AFTER HAVING BEEN BREATHED UION

leaf underneath is dark green, in comparison with that which was left exposed and unprotected. That is light green.

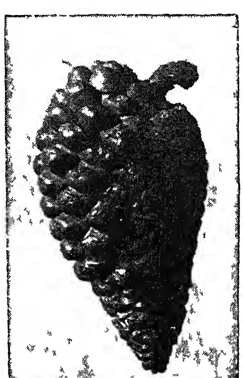
A reference to a simple diagram in this chapter will explain this We find that when the light is diffused (7, page 2452), the chlorophyll granules so arrange themselves as to cover those walls of the cells on which the light falls perpendicularly. This gives such portions of the leaf a dark green appearance. When such a cell becomes exposed to direct sunlight, the granules leave these walls parallel to the upper surface of the leaf, and accumulate on those which are parallel to the direction of the light (2). The tissue, as the result, assumes a much paler color.



DEVELOPMENT OF A WINDOW-PLANT, BEGONIA, ON THE SIDE TOWARD THE LIGHT

We have already, in previous chapters, referred to the movements of cotyledons, and what was then said should be read also in connection with our present topic. A word or two may be added, however, to the remarks already made in connection with leaves, concerning the movements of certain *compound* leaves, which exhibit interesting changes of attitude in such places where they are exposed to considerable cooling during the night temperatures.

During the ordinary hours of sunshine such leaves may be placed more or less parallel to the surface of the ground, with the upper surface open to the sky, and thus catching the direct rays of the sun. It is obvious that if the leaf were to remain in this attitude during the hours of the night, there would be great loss of heat, on account of radiation toward the upper air. The intelligence of the plant, if we have agreed to understand that term, here shows itself by the leaflets which compose the compound leaf folding themselves together either upward or downward, according to the species concerned, so that their broad aspect is placed vertically In this manner there is much less loss from radiation than there would otherwise be



PINE-CONE DEVELOPED ON ONE SIDE

We may now turn our attention to an entirely different class of plant movement, namely, that which is associated with climbing plants, of which there are a large number whose stems are not sufficiently woody in texture to maintain a vertical or erect attitude In a plant which has such a nature, one of two things may happen. the stem of the plant may continue to grow along the surface of the

ground bending or arching, perhaps, as it does so, but coming in contact with the soil at intervals Such plants have what are termed prostrate stems On the other hand, however there are a number of species which in their efforts to reach the erect attitude have developed various structures — some already considered—which enable them to grasp any neighboring object that may afford a means of support, and to this object the plant may attach itself

Our illustrations show examples of such plants in the tendrils of the bryony, in the coiling petiole of the common tropæolum or nasturtium and wild clematis, both of which are supported by their leaves The peas and the vetches also exhibit their climbing movements in virtue of the modifications by which their leaves pass into the very thin threads or tendrils that wind so readily round any object sufficiently near (see page 2072) Another good example is that of the hop but in this case the whole plant participates in the movement, the entire stem twisting to the right These various examples may be seen in our illustrations

LYSIMACHIA, A PROSTRATE GROWING PLANT

Next we may turn our attention to an entirely different aspect of what we have referred to as plant intelligence In a previous paragraph we made some reference to the movements which take place in plants during the hours of night, to which the name of "sleep movements" has been given, and it will be remembered that these consisted in the adoption of certain attitudes of the leaves or leaflets A somewhat similar phenomenon is to be noted in connection with some plants that exhibit these sleep movements, and also in others that do not We refer to plants known by the general name of "sensitive plants", from their different manifestations of this sensitive phenomenon A number of the plants which assume the sleep position in the night exhibit a similar movement when they are either shaken or merely lightly touched, and, as a matter of fact, they appear to be even more sensitive to this disturbance than to darkness The onset of a very slight breeze of air may be sufficient to cause the leaflets to fold up In one well-known plant which grows in India (*Oxalis sensitiva*) so delicate is the apparatus concerned that even the slight disturbance caused by anyone walking in the immediate neighborhood is enough to produce folding in the leaflets, and they open once more when the person moves away Probably it was this phenomenon of the shrinking, as it were, of the leaves of certain plants at the approach of man that was responsible for their first being named sensitive plants

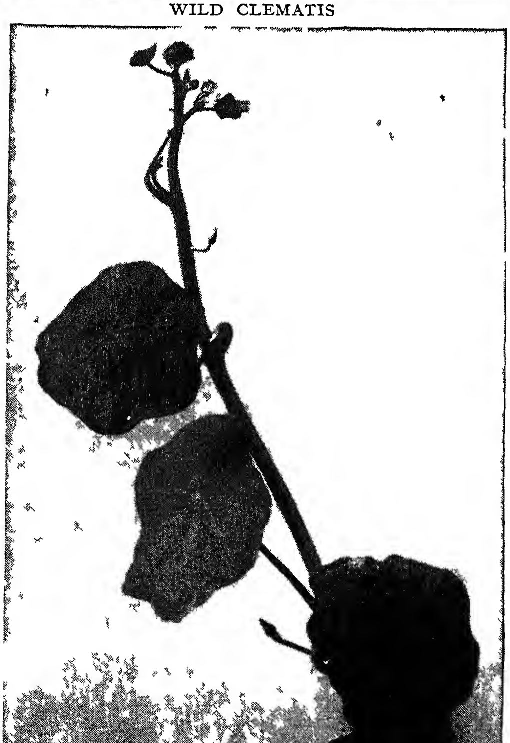
Although this curious change occurs in some of the same plants that adopt the sleep position at night, it is not to be therefore inferred that the two things are the same The attitude of the leaf is determined by the condition of a little cushion of tissue called the pulvinus This cushion remains quite rigid in the sleep position, while, on the other hand, it undergoes a very remarkable change in the movements produced by shaking the plant It becomes less turgid by discharging some of its water into another part, and the result of this is to cause a bending of the leaflet quite unlike the position which the leaf assumes during sleep

Under natural conditions practically the only two things which stimulate the proto-

FOUR EXAMPLES OF CLIMBING PLANTS

WILD CLEMATIS

THE TWISTING STEM OF THE HOP

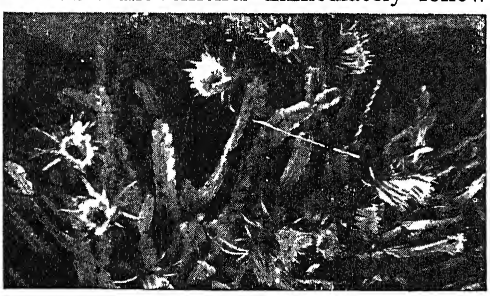


THE COMMON TROPÆOLUM

BLACK BRYONY

THE FLOWERS OF SAND-SPURRY, FULLY EXPANDED IN SUNLIGHT BUT CLOSED DURING RAIN

plasm to act in this way are the action of the wind, and, still more emphatically, perhaps, the irritation caused by the falling of drops of rain on to the leaf. In the Indian plant already referred to, most remarkable movements immediately follow

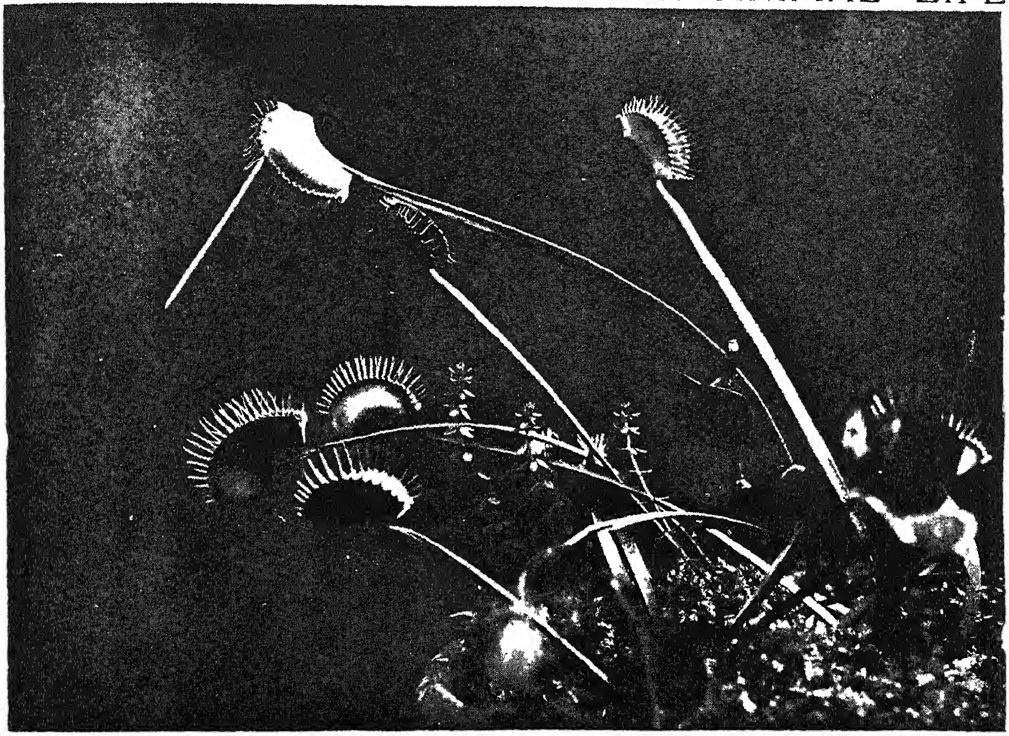


THE CEREUS, THAT BLOOMS ONLY BY NIGHT

a shower of rain. The leaves which first come in contact with the drops fold together downward, but not only do these leaves do so, but actually, also, those in closest proximity to them, even though no actual drops fall thereon. Well might such a plant be termed "sensitive". Even the leaf-stalk, which bears the mass of leaves, bends in the direction of the earth; and the practical consequence of these movements is that the drops of rain-water flow over the bent stalk, and over the hanging leaves, so that all the moisture is immediately drained off, and none remains upon the surface. No better example can be imagined illustrative of plant intelligence, or movements directed by some principle toward the attainment of a definite purpose.

Very similar processes are seen in the leaves of the sundew, and in those of Venus's fly-trap, as well as in some of the mimosas. The actual movements are not identical in all these cases, but they are produced by the same sort of influences, and for precisely analogous purposes. The freeing of the plant from rain-drops, however, though obviously one of the objects in these movements, is not the only one. This may be concluded from the fact that quite other conditions than rain produce

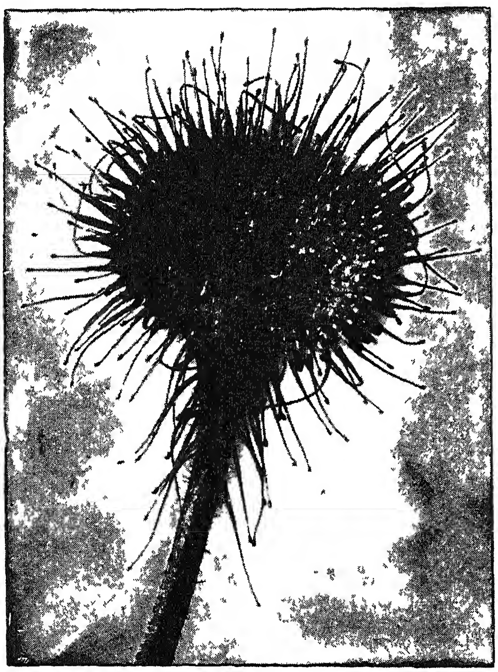
FLOWERS OF THE ENGLISH DAISY, CLOSED AT NIGHT BUT OPEN IN FULL DAYLIGHT



THE VENUS FLY TRAP, SHOWING ONE LEAF CLOSED ON A PIN

AN AUSTRALIAN SUNDEW WHOSE LEAVES CAPTURE AND DIGEST SMALL INSECTS
Mexican sundews of a similar nature grow in our peat-bogs

the same movements, particularly such factors as hot, dry winds, impregnated with particles of dust or sand. Here it is obviously to prevent excessive transpiration that the leaves fold together. So we may safely conclude that several different advantages accrue to the plant in virtue of the powers of movement we have been describing. At night the loss of heat by radiation is minimized. In the heat of the day extreme transpiration is kept in check. In wet weather, injury to the leaves, or possibly to the whole plant, which might collapse under the weight of accumulated water is prevented.



A HIGHLY MAGNIFIED LEAF OF SUNDEW

A still more subtle object has been suggested by some writers, namely, that the sudden movements of the leaves, which result from the vicinity of an animal that might otherwise feed upon the plant, may have the effect of creating such astonishment, or even fear, in the mind of such an animal that it would refrain from its contemplated meal. Whether such a thing actually occurs or not it is difficult to say, though it seems improbable. Nevertheless the suggestion is a very interesting one.

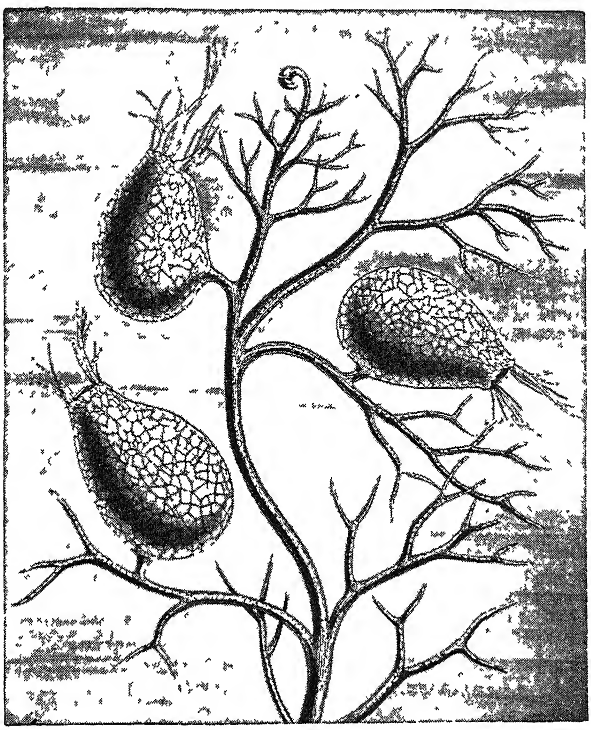
A movement which may be observed in almost all flowering plants is that which takes place at the onset of daylight, or at some varying period during the day afterward. This is the opening of the passage to the interior of the flower. Very detailed observations have been made on the times at which this separation of the petals takes place, and the following examples, quoted by Kerner, may be noted here. In the case of the honeysuckle, the whole series of movements in the process begins by the lowest lobe of the corolla folding back this being followed by the same thing in the other lobes, which liberates the stamens, and they spread out like fingers. This series of movements takes about two minutes. The evening primrose is still more rapid in its opening, the petals springing apart, and being wide open in half a minute. This may truly be described as the bursting open of the flower. In some cases this opening occurs quite quickly enough to be followed with the naked eye, and in one or two instances is accompanied by a slight noise.

With regard to the times during the day when these opening movements may be noted, Kerner gives the following instances: "There are flowers which open so early in the morning that they greet the first rays of the rising sun with fully expanded corollas. That common garden climber, the morning glory, *Ipomœa purpurea*, opens its buds at 4 A.M. Wild roses also open between 4 and 5 A.M. Between 5 and 6 many species of flax open. Between 6 and 7, willow-herbs; between 7 and 8, *Convolvulus arvensis* and *C. tricolor*. Between 8 and 9, many gentians, speedwells and wood-sorrels, and the Himalayan cinquefoil. Between 9 and 10, most tulips and opuntias open; between 10 and 11, the century and chaffweed. Between 11 and 12, *Potentilla recta*.

"From noon till evening comes a long interval. No plant is known in our latitude which, under ordinary circumstances, opens during the afternoon. Towards sunset, however, it recommences. About 6 P.M. the honeysuckle opens, shortly followed by the evening primrose and campion. Between 7 and 8 P.M., *Hesperis*

matronalis and *H. tristis*, the Marvel of Peru, a few catch-flies, and several thorn-apples. Between 8 and 9 more catch-flies, a woodruff, and a species of tobacco. Between 9 and 10, the Queen of the Night, the Mexican cactus, opens."

When we come to consider the subject of plant defenses we shall have to make reference to poisonous and insectivorous plants. One or two of these, however, must be noted here from the point of view of their movements. We may take those to which we have already referred. All of the sundews are excellent examples of plants whose movements are directed to the capturing of small insects. The plants themselves are to be found mostly in peat bogs. There are some forty species of sundew, all of which show as their most conspicuous character a slender red filament, that is club-shaped at its free end and carries a refractile globlet of fluid. These filaments project from the upper surface of the leaf, the under aspect of which is smooth, and very often rests upon the damp ground. The filaments have been compared in their appearance to pins stuck in a cushion. They are various sizes, the shortest being in the middle of the leaf, the longest at the outer edge, and each leaf carries about two hundred of these little filaments. The club-shaped swelling at the end is in reality a gland, which secretes a clear globlet that looks very like a drop of dew, but is really a sticky, viscous substance, from which it is impossible for the insect to extricate himself.



THE TRAPS OF THE BLADDERWORT THAT CAPTURE TINY AQUATIC ANIMALS

A wonderful example of plant intelligence is to be found here. The movements we have mentioned above in connection with wind and rain and dust are utterly ignored by the sundew. Experimentally, one may irritate these filaments with minute particles of ordinary foodstuffs, such as sugar, or with solid particles of sand, and so forth, and the only result is to increase the secretion of the gland, which assumes an acid reaction. The leaf itself, however, does not move, nor does there follow any attempt at digestion.

Let a small insect, however, in its search for honey, impinge upon the leaf and touch the gland, and — wonderful to relate — the composition of the secretion is at once changed, in so far as it becomes a digestive ferment, the object of which is, of course, to appropriate the unfortunate insect as food. Remarkable movements take place in the filaments, or tentacles, and they close in, so to speak, as the tips of the fingers would do if bent towards the palm of the hand as in grasping a baseball.

Gradually all the filaments bend over toward the insect which has been caught in the sticky, glandular secretion, and in a time varying from one to three hours all of them are found bending upon it. No matter where the insect may alight, the tentacles move down upon it exactly to the right spot, whether it be in the center or otherwise. Should there be two insects for the same leaf, at the same time, in different parts, then some tentacles will converge on the one, and some on the other.

The result of the whole process is that the captured little creature is covered with secretion and digested. The whole process of absorption is complete in a couple of days. What is left behind is carried away by the wind when the tentacles reassume their original attitude. Small midges are the usual victims of the sundews, but flies, and ants, and beetles also suffer a similar fate. As many as thirteen different species of captured animals have been found on a single leaf at the same time.

The really interesting fact about these wonderful, intelligent movements is not merely that they contribute to the nutrition of the plant, but that the movements take place in tissues other than those which are actually the first to be stimulated by the insect. In other words, there is a transmission, or carrying, of the original impulse from cell to cell through many cells at a speed which can be actually measured. This suggests at once to the mind an analogy to the transmission of a nerve impulse from the brain to a distant muscle in the arm or leg. How sensitive the leaves of the sundew are may be imagined when it is stated that "a particle of a woman's hair, 0.2 mm. long, and weighing 0.000822 mg., when placed upon a gland of Drosera rotundifolia, caused a movement of the tentacle belonging to the excited gland". A similar experiment on the human tongue would fail to give any indication of the presence of the hair, though the tip of the tongue is very sensitive. In the water may be found floating masses of bladderwort, so named because of the small bladders, easily visible to the eye, which they bear. One might off-hand assume that the "bladders" existed for the purpose of assisting the plant to hold itself more erect in the water. This is not the case. Instead of serving as floats, these little structures are traps for the capture of small aquatic animal life. An opening exists at one side of a bladder. Around this opening is a set of radiating hairs set diagonally outward. These serve to guide the approaching victim into the mouth of the trap. The opening is provided with a hinged transparent door which opens inward but not outward. Once a creature has wholly or even partly entered this door his doom is sealed. If he has gone completely in he cannot get out, and if he has gone part way and attempts to withdraw the door closes and the harder he tries to draw away the tighter he closes the door. Once captured the victim must die and become food for the captor.

MAMMALS IN THE WATER

The Strenuous Life of Land Animals that
Have Become the Monsters of the Seas

HOW THE LEGEND OF THE MERMAID AROSE

FEW types of animal life present a greater puzzle to the non-student of nature than the water-beasts we have here to consider — the whales, the sirenia, etc. Glancing at the question for a moment, the observer assumes, perhaps not inexcusably, that they are great fish — whales the largest of all fish, the sirenia (that is, the manatis and dugongs) their smaller kin. And upon this assumption he must take it for granted that these "fish" have always been denizens of the waters, and have developed from other fish. What a surprise it must be to such a man to learn that the whale is as truly mammalian as the human species! That it is hot-blooded, brings forth its young alive, suckles its young as a cow suckles its calf, cannot breathe under water, and that, should it be prevented from rising to the surface to renew its supply of oxygen, it would drown! This is true of whales and dolphins of every species, and equally true of the sirenia.

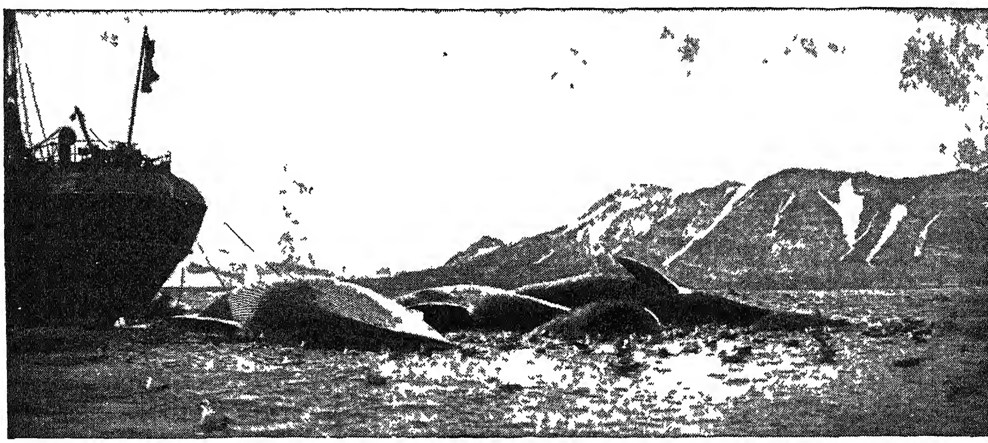
Corrected on these points, the non-expert may be forgiven if he cling to error and say: "Well, these are surprising developments of fish life!" It is not unnatural to so regard them, but although the cetacea and the sirenia have attained full development in the water, they did not originate there. There were whale-like ancestors which, after ages of carnivorous feeding upon the margin of ocean and river, produced offspring that put out to sea and did not come back. And the same is true, in a way, of the sirenia. Neither whale nor manati nor dugong could now make a living on the land; their food and dwelling-place are both in the waters. But all are the descendants of land animals.

Of course, all external trace of their association with life on land has been obliterated from the anatomy of both types of animal, but the sirenia retain the characteristic head of the terrestrial mammal. No member of the order has developed the back-fin common to many of the cetacea. In both, respiration is highly specialized, as in the crocodilia, to enable the animals to swim beneath the surface with mouth open without water entering the lungs. Although the fact is not obvious from superficial appearances, both orders have the same number of vertebræ in the neck as other mammals; the short, imperceptible neck of the huge whale has as many vertebræ as that of the giraffe and the rabbit. Both whales and the sirenia retain, hidden within the thick, fleshy flappers, their four or five fingers, but only vestiges of the hind limbs with which their ancestors once roamed the earth are now to be discovered. There is one peculiarity common to the sirenian and the dolphin tongue: each is furnished with curious pits or depressions, in which the presence of numerous ganglionic cells suggests a connection with the sense of taste.

For the sake of many a romantic fancy, it is a pity that manatis and dugongs are such unlovely beasts. For these are the mermaids and mermen of old seafaring legend upon which poet and story writer have fastened. Dull, heavy, almost repulsive-looking animals, how came they to be thus idealized? The sea-cows — such being their popular description — have the teats high up on the breast. When suckling her young one, the female raises her head and breast out of the water, and, sup-

porting her calf by means of her flippers, feeds it. The action, witnessed from a distance, must have seemed human to early navigators and they would bring home tales of water-dwelling women nurturing their babes in the midst of the waves. Poetic fancy would do the rest, albeit not all legends of mermaids represented the heroine as lovely. The glistening tail of the conventional mermaid is a figment of the fancy. Needless to say, no mammal has scales, and the tails of the sea-cows, like those of the whales, are horizontal, not vertical as is the case with the tails of fish. In place of features resembling the human, the sea-cows have heavy, bristly jowls, with nostrils set at the apex of a triangular-shaped muzzle, and those nostrils are fitted

The American manati inhabits all the large tropical rivers of South America, abounding in the Amazon and the Orinoco and their huge tributaries almost to their mountain sources. It is equally numerous in estuaries and rivers of the Guianas and along the eastern coast of Central America, and in Cuba; but in Mexico, Louisiana and Florida it has now become very rare through the persecution of hunters. The hide is valuable, the flesh is excellent, and the oil derived from it is soft and clear, does not become rancid and is highly prized. These animals are perfectly harmless, and have, indeed, little power of resistance. They travel in small bands or family parties and remain near shore, feeding on various aquatic plants,



CAPTURED WHALES MOORED TO THE STERN OF A NORWEGIAN STEAMER OFF SPITZBERGEN

with valves which enable the animal to close them against the intrusion of water when diving below the surface.

The manatis have the tail rounded; that of the dugong is crescent-shaped. In the manati the upper lip is prehensile, and becomes the grasping instrument by means of which leaves and other vegetable food are introduced into the mouth without the assistance of the under lip. To effect this purpose, the upper lip is divided into two fleshy pads, which, on being brought within reach of food, at first diverge, then close upon the object, firmly seizing and securing it. The action of this lip is like that of the jaws of the caterpillar, in which there is a continual lateral opening and shutting during mastication.

supported in the water while doing so on the strong tail. If disturbed they sink out of sight very silently and swim away, their nostrils closing like valves when they go under. They seem to live in permanent pairs, and one or two young are born to each pair annually. Captive specimens have shown not only an affectionate nature, but considerable intelligence.

The dugong, of which there is only one species, as against three species of manatis, ranges from eastern Africa to Australia, from Ceylon to the Andaman and Nicobar Islands. It never ventures into rivers, but feeds upon seaweeds and marine grasses, but otherwise its habits differ little from those of the manati. Both animals attain a large size—from 5 to 8 feet long, with a

A MONSTER MAMMAL OF THE DEEP SEAS

Photo Wide World Photos

HUGE "BLUE FIN" WHALE WEIGHING 80 TONS CAPTURED OFF CATALINA ISLAND, CAL.

girth of 6 feet — and both are quite helpless on land The manati would seem to be the more generalized animal, for it can live in salt water or fresh, but the dugong is said to find life impossible in any but sea or brackish water. Several extinct species of sea-cows have been traced, of which the northern sea-cow, a very much larger animal than the existing species, and inhabiting far colder waters, was found in thousands on the shores of the Commander Islands about the middle of the eighteenth century. A single living specimen would be worth a fortune today.

A HERD OF BOTTLE-NOSED WHALES CAPTURED OFF THE SHETLAND ISLANDS

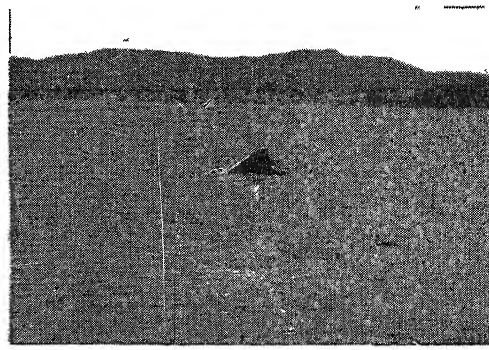
When we come to the whale family we reach a group more ample than would at first sight appear. In it are embraced the dolphins, the porpoises, the grampuses; and whales such as the "sea-unicorn", which are whales only to the initiated, and the "black fish", which are not fish at all. The existing members of the group are an order to themselves, divided into two sub-orders, of which the first covers the whalebone or true whales, divided into five genera. The whalebone whale has no teeth, and has been regarded as derived from a source different from that which gave rise to the toothed whales. But before birth the embryo whale has two sets of teeth, corresponding with the milk-teeth and permanent dentition of other mammals. Those of the earlier set are absorbed into the jaw before the birth of the animal. They present characters resembling the teeth of the zeuglodonts, the extinct, semi-armored, whale-like animals through which we trace the descent of the existing order. In the baleen whale the nasal aperture is double, as in other mammals, but in the sperm whales it is a single orifice.

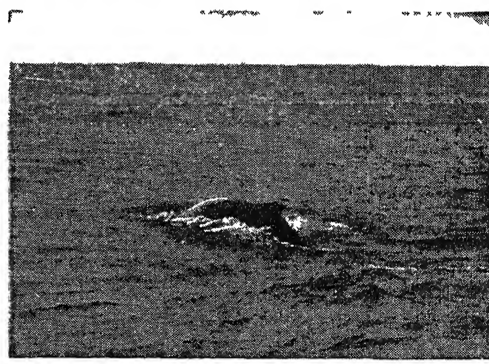
The whale is one of the most striking examples of special adaptation to a particular mode of existence. It is the finest "submarine" in the world. The human diver with the best of equipment, can work with difficulty at a depth of 160 feet or so below the water. At that depth he bears a pressure upon the body of about 70 pounds to each square inch. Now, there is fish life in the sea that can exist only in the middle depths and is crushed by pressure if forced down into the depths below its habitat. These same fish, brought to the surface, burst like pricked bubbles. But the whale is known, after coming up to breathe, to descend perpendicularly nearly 5000 feet. At that depth a large whale must sustain a pressure of close upon 140 tons on every square foot of its body. It swims from

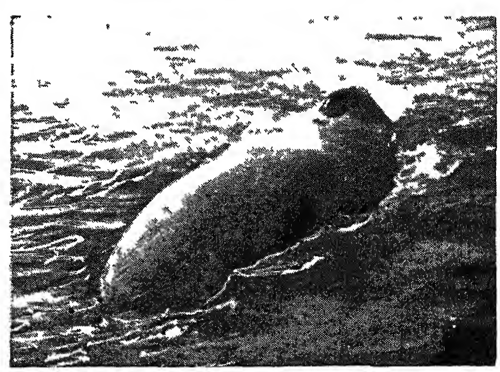
polar seas to tropical, the heat of its body conserved by the enormous blanket of blubber wherein it is invested, and that blubber serves also, it is assumed, to enable the animal to withstand the enormous water-pressure it has to endure.

The distinguishing feature of the baleen whale is, of course, the baleen or whalebone which in these animals takes the place of teeth. This baleen consists of horny plates, frayed at the edges into a kind of fringe. These plates, arranged along the two sides of the upper jaw, vary in size, being shortest at the front and back of the mouth, and at their greatest length — some 10 to 12 feet — along the center reach of the arch jaw. When the mouth is closed these plates of baleen lie flat along the jaw, with the points directed towards the throat. When the mouth is opened the plates are automatically erected, the principle of mobility being the same as with the fangs of the snake. Now, this huge mass of baleen, which in the Greenland whale may number close upon 400 plates to each side of the jaw, and weigh from a thousand to three thousand pounds, is simply the vast sieve wherein the whale entraps its food. The jaws may be twenty feet in length, and are thrown wide open as the animal swims into a swarm of teeming crustaceans and molluscs floating upon the surface of the water. The jaws close upon a vast volume of water in which multitudes of these small animals are swimming. As the jaws come together the water drains out at the side, but the life that it contains is enmeshed in the whalebone strainer, and directed towards the throat. Thus this monster of the deep — fifty, sixty, and more feet in length, and weighing many tons — feeds upon quite minute forms of life. A shark can swallow a fair-sized sack of coke, but a "right" whale would strain at a sprat and choke deplorably over a herring.

The black whale, or Nordcaper, is a smaller animal than the Greenland; it is more active and makes a fiercer fight for life; but from Norway to Japan, from Australia to Spitzbergen, it is remorselessly hunted, as indeed the members of the whole tribe of whales are, and these aquatic mammals are among the doomed animals of the world. The black whale carries a puzzle upon its head — a series of horny, honeycombed excrescences known as the "bonnet." This was believed to be caused by the whale's scraping its nose against rocks to rid it-


A WHALE IN THE ACT OF FEEDING

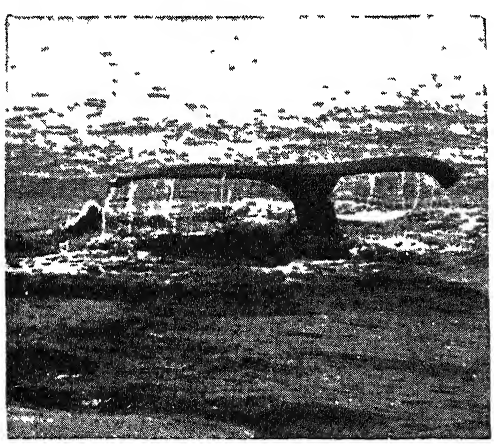

A WHALE ABOUT TO DIVE


A HUMPBACK WHALE WITH NOSTRILS FULLY EXPANDED IN BREATHING

self of the barnacles that infest it. But, inasmuch as the cells of the bonnet are found to be filled with whale lice, which are, in fact, crustaceans of the genus Cyamus, and these crustacea prey upon the larva of barnacles, the origin as well as the pur-

pose of the bonnet may have been misjudged. That the excrescences with their cells came into being as an asylum for lice to police the hide of the whale against its enemies is hardly seriously to be asserted, but many mysterious processes are reflected in the story of inherited tendencies

Sandwiched between the Nordcaper and the big gray whale we have the pygmy whale, but we must not infer from the name that here is something to be added to the list of possible pets for the artificial salt-water lake, the pygmy whale averages from 15 to 25 feet, rather less than half that of the gray whale. The latter is now confined to the North Pacific.



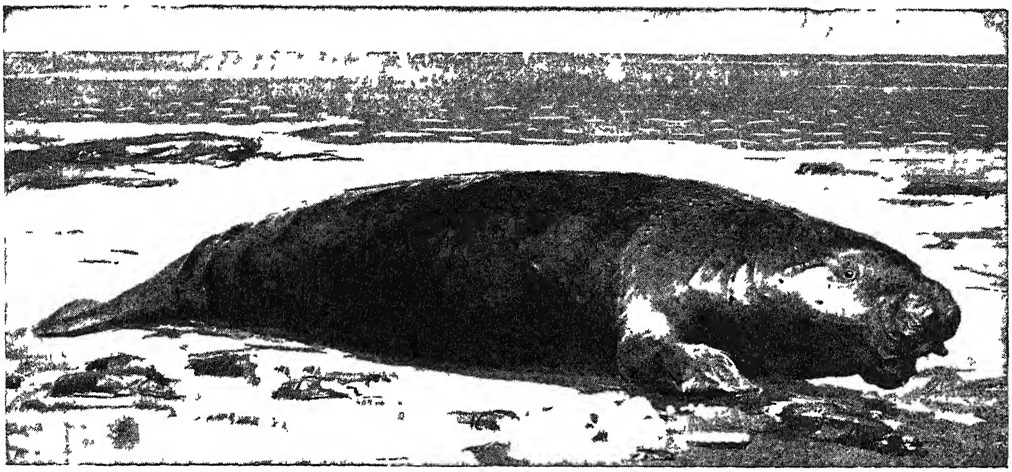
THE TAIL OF A DIVING WHALE

Much the same proportions are attained by the humpbacked whale — a name that relates to the massy prominence on the back of the whale by which the fin is supported. This whale has a wide distribution, and is an occasional visitor to New England shores. It is hunted everywhere. The results of the chase are somewhat of a lottery, for while the biggest yield of oil may represent as much as seventy-five barrels, another whale will produce but an eighth or ninth of that total.

Next to the humpback come the rorquals, or fin-backs, of which four species are recognized. They are the commonest of all whales. The fact that they produce only the coarsest and shortest of whalebone and the smallest quantity of blubber may be not unrelated to their comparative immunity in the past. But, on the principle that half a loaf is better than no bread, the whale-hunter has of late turned his attention more closely to this whale, and by better organized methods of chase and commercial processes has brought it more prominently into the profit-yielding items of his balance-sheet.

The rorquals are less restricted in the matter of swallow than the Greenland whales, subsisting upon fish such as the herring and pilchard. These, not worth swallowing in twos and threes, are received into a large collapsible pouch in the throat until the requisite cargo has been collected, when the whole are swallowed together. It is the lesser rorqual which, gamboling about moving ships, is commonly mistaken for the young of the greater whales. But an adult lesser rorqual ranges between 25 and 30 feet, with occasional examples of greater size. The common rorqual, however, varies between 60 and 70 feet. The immense speed and strength of this species kept them moderately safe until latter-day modifications of whale-hunting equipment trebled the effectiveness of man's attack. But it is the next species, the blue rorqual, or Sibbald's fin-whale, which claims preeminence for size. This is the veritable leviathan, 70 to 90 feet in length, and of bulk proportionate. It is the largest living animal in the world, and until the advent of explosives in the chase, held its own pretty well against its human enemies.

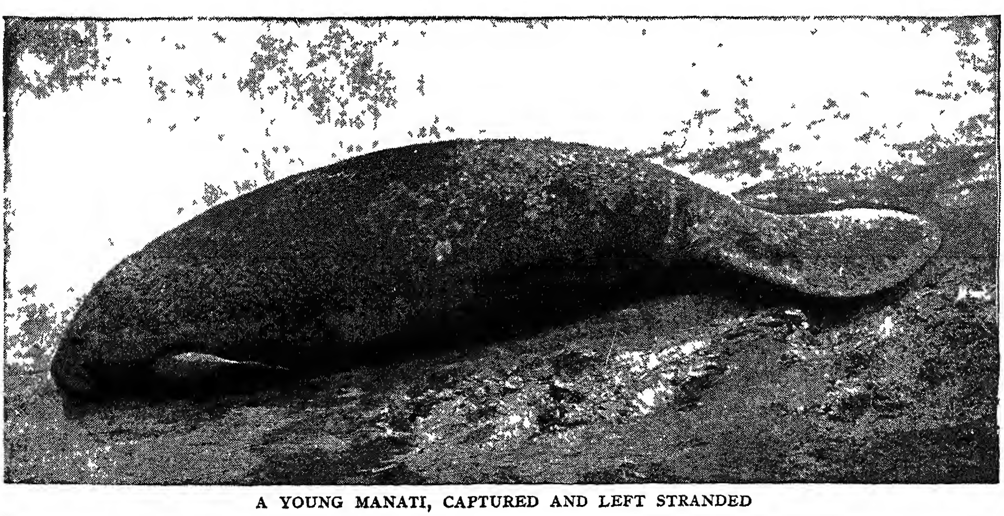
Passing now to the toothed whales, we note first the huge sperm whale, or cachalot, which rivals the Greenlander in size, and is an incomparably more formidable animal. The baleen whales are quite inoffensive creatures, never dangerous to man save when in their death throes, and then only by the violence of their agony, in which they may involuntarily overturn a boat. The sperm whales, however, are more militant, as is perhaps to be expected of animals armed, as to one jaw, with the most formidable array of teeth. In former days both jaws of the sperm whale were furnished with teeth, but the existing species never develop more than vestigial evidences of dentition in the upper jaws. The sperm whale is the giant of all the toothed cetaceans,



THE DUGONG, THAT GAVE RISE TO THE LEGEND OF THE MERMAID

weighing, for a 60-foot specimen, about 70 tons. These monsters are, of course, becoming more rare. So merciless is the persecution to which they are submitted that they are vanishing from the waters to which the stress of competition so long ago drove them.

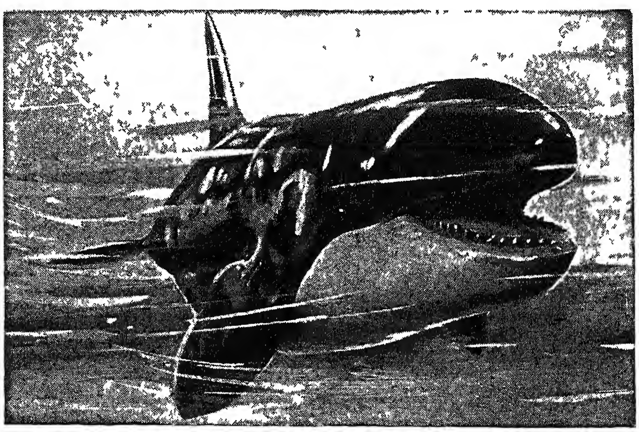
The cachalot is a native of warm seas, but in summer may roam far north. It is a great traveler, as is evidenced by the fact that specimens have been taken in the Atlantic still carrying the harpoons discharged into their bodies while they were in the Pacific. The female produces one young one at a birth, but that infant may measure from 11 to 14 feet! The female cachalot displays great solicitude for her young, as, indeed, do all female whales, and evinces also a good deal of intelligence in protecting them. How the cachalot procures its food cannot be told, as the animal feeds deep beneath the surface, but the nature of its diet is known. Although considerable quantities of fish are taken, squids and cuttle-fish constitute the chief source of the monster's meal. Tremendous combats between cachalots and giant cuttle-fishes have been witnessed. Cuttlefish, huge and hideous enough to challenge comparison with the most fanciful pictures of the old writers, have been seen madly grappling the titanic bulk of a whale, the terrible tentacles, like a series of colossal boa-constrictors, seeking to crush the enemy.



A YOUNG MANATI, CAPTURED AND LEFT STRANDED

But the whale evinces no apparent discomfort; he simply eats his bonds one by one. It is only by hunting the cachalot that we can arrive at an estimate of the dimensions of these fearsome cuttles of mid-ocean. The whale, when mortally wounded, disgorges its last meal, and at such times pieces of the arms of cuttle-fishes six feet in length and eight feet in circumference have been recovered — a significant suggestion as to what must have been the full dimensions of the unmutilated cephalopod.

Ordinarily the sperm whale is quite harmless until attacked. Even then the first impulse of the animal is to seek safety in flight. But it is at such times that danger is to be apprehended, for when wounded the animal, with tail or jaws, will attack and smash everything within reach, and, after flinging boat and men into the air, will chew the timber of the wrecked boat into matchwood. Not a few instances are on record of cachalots having attacked ships. A singular example comes from Australian waters where a brigantine, deeply laden with timber, was assailed by two cachalots. At the last moment one of the animals shirked the unprovoked combat, and dived. The other tilted head-on at the ship, and struck with its head such a blow that the vessel was caused to reel from stem to stern and had its side smashed in. But these are, after all, exceptional cases, and the sperm whale is a long-suffering animal.


THE KILLER WHALE, OR GRAMPUS

Although it lacks the inestimable baleen, the cachalot is a precious harvest to its captors. It yields the little-understood ambergris, which, sometimes found floating upon the water, sometimes in the body of the animal, is worth \$20 to \$30 an ounce. The more dependable profits, however, are the blubber and spermaceti. The latter occurs in enormous quantities in a huge cavity at the back of the head. After treatment, it becomes superfine candles for altar and shrine; it salves our hurts when made into cold creams, ointments and the like. The blubber, rendered into oil, accompanies us into the bath, in the form of the best soap.

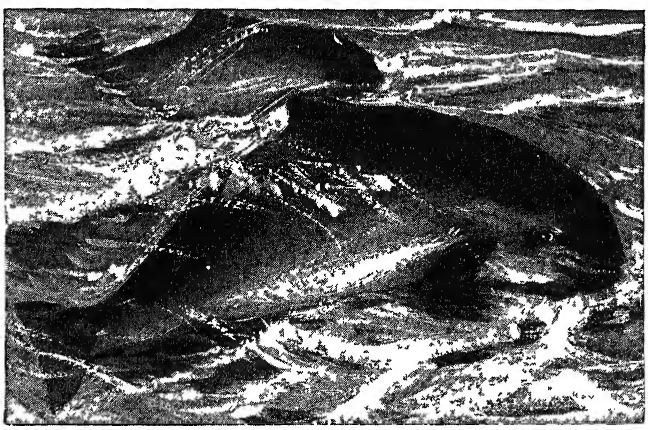
The sperm whale is not alone in yielding these substances; there are other whales, the bottle-nosed and beaked whales of various species, which are made to contribute their quota. The bottle-nosed whale, which yields a finer oil than the great cachalot, is even more persecuted than some of its fellows, and is now swiftly verging upon complete extinction. Many female whales stay by a wounded companion, but this solicitude extends to both sexes of the bottle-nosed. A herd is easily approached by a ship, and when one is wounded the remainder swim round it in great concern so that one after another can be attacked in turn until the entire school is killed.

Men have been hunting the whale for a thousand years, and it is computed that in that time a million victims have been secured. But latterly the calling has become more closely organized, and the hunting keener than ever. Shore stations have sprung up in all directions, where blood, bones and flesh, as well as blubber and spermaceti, are utilized. From the point of view of the trader the change is excellent, but the nature student cannot but view with deep regret the seemingly inevitable extinction of these leviathans of the deep, unless someone, unmindful of the scorn of those who deem it affectation to pity a whale, makes a stand for these animals, as has already been done for seals and sables.

The toothed whale sub-order, as we have noted, is an extensive one, and some of the groupings may seem a little curious, for among the porpoises we have the narwhal (or sea-unicorn), the killer whale, the beluga (or white whale), and the blackfish (or pilot whale). The first named is that curious creature which has converted the tusk on the left side of the upper jaw into a massive spiral weapon of offense and defense, yet remains toothless. This abnormal tusk, which is of dense ivory, and may measure from 7 to 8 feet, with a circumference of 7½ inches at the base, is believed not to be employed in securing prey, but in combat, after the fashion of the antlers of the deer. The beluga yields a good leather, which is commonly sold as porpoise-hide.

The killer, or grampus, is the swiftest and fiercest of all the order, and the greatest glutton. Two or three combine to attack a Greenland whale, and devour it alive, darting into its mouth and eating out its tongue piecemeal, or tearing great masses of flesh from the body of the quivering victim, which seems powerless to resist them.

The bulk of the dolphin family are of marine habits, but some of them frequent rivers. The Gangetic dolphin, or susu, is essentially a river animal, inhabiting the Indus, the Brahmaputra and Ganges from the sea to the mountains where they rise. The Amazon and La Plata have each their fresh-water dolphins, while in the Irawadi there is this peculiarity to be noted: in the upper waters are numerous representatives of a species (*Orcella fluminalis*) which never descend to the estuary, while in the estuary is a closely allied species (*O. brevirostris*) which never ascends the river beyond the influence of the tides.

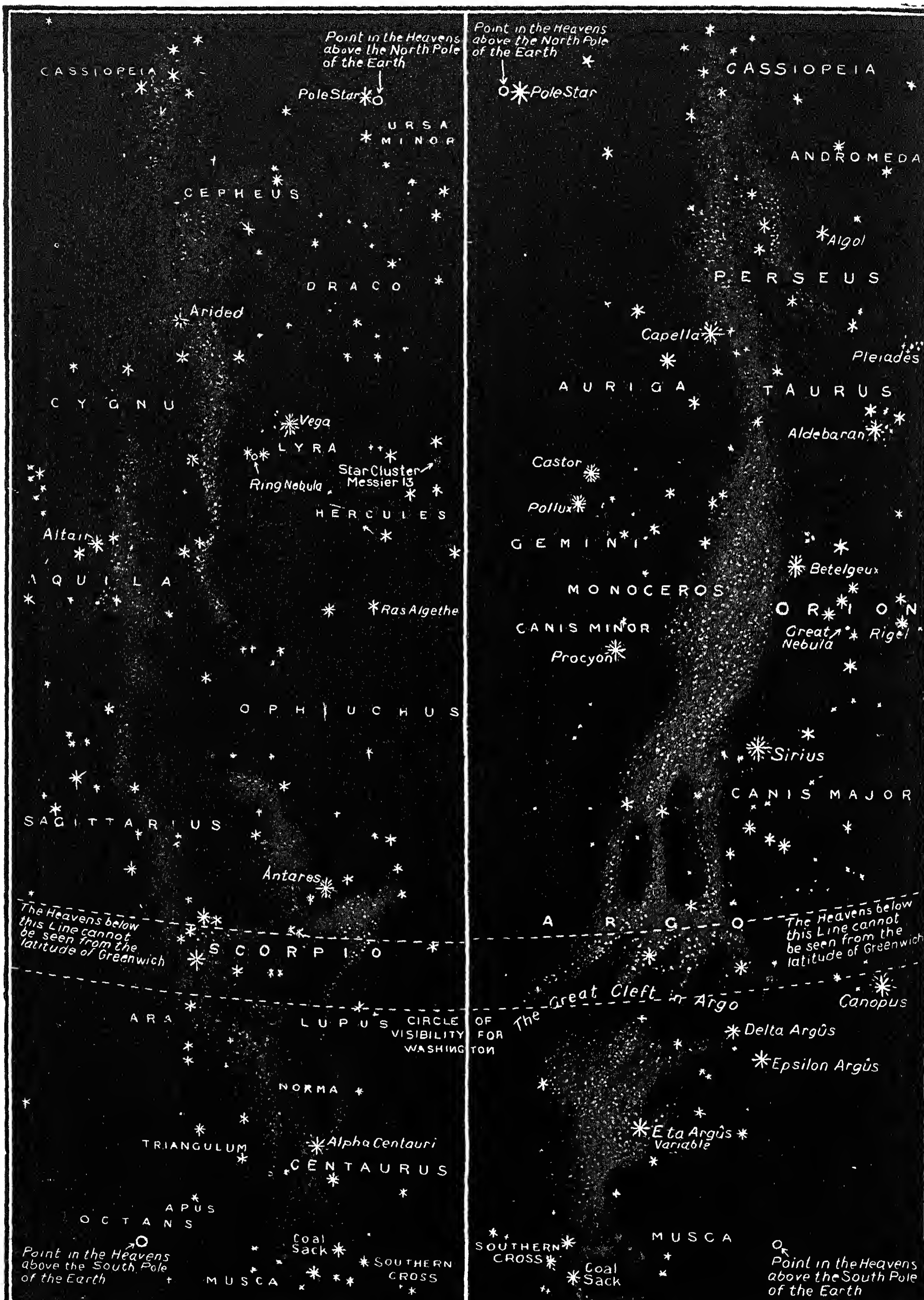

COMMON PORPOISES

Porpoises, which are grouped with the dolphins in one sub-family, are the commonest of all cetacean visitors to the northern coasts, and are to be found at times high up some of our tidal rivers, both north and south. But the sea is their proper home. The porpoise may readily be distinguished from the dolphin. It is smaller, and has a rounded muzzle without any suggestion of a beak.

Whaling has been engaged in since 1712 by vessels from New England ports, especially Nantucket and New Bedford. In the earlier years whales were often sighted from shore and pursued in small boats, but a whale is a very unusual sight nowadays from any point on shore. Occasionally a finback whale gets stranded along the Atlantic coast but most people who spend their summers at the seashore have to be content with the infrequent visitations of dolphins or porpoises passing up or down the coast just outside the breakers. The most common of the so-called "porpoises" is the bottle-nosed dolphin, the common dolphin being seldom recorded, and the real harbor porpoise seldom coming as far south as New Jersey.

This is the creature that often attends ships plying along our Atlantic coasts and is most frequently called "porpoise". In "schools" of varying size they sport alongside, often close to the prow, as though piloting the ship on its way, or again several hundred yards away when they can be seen only at intervals when in their undulating course they raise their pointed fins or even their arched backs above the surface. Occasionally the powerful fluked tail is flipped into the air and the entire body may be exposed for a moment as the huge mammal dives into a wave.

A CIRCLING ZONE POWDERED WITH STARS



THE PATH OF THE MILKY WAY THROUGH THE HEAVENS, SHOWING THE NEIGHBORING STARS

The Milky Way, when seen from the earth, appears as a great ring of stars. These two drawings show the two semi-circles of the Milky Way as they extend from the region of the Polar Star to the region of the Southern Cross on each side of the apparent sphere of the heavens. It will be noticed that the bright stars congregate near its region, and that there is a characteristic harmony in the way in which the wisps appear to project into space, suggesting some common cause for this appearance throughout the whole galaxy

THE WONDERFUL MILKY WAY

Unsolved Problems of Starland. Sounding the Vast Depths of the Sidereal Universe

WHAT IS THE UNREAD PLAN OF THE HEAVENS?

EVERYONE knows the Milky Way. It is one of the most striking sights of a clear night, for only on clear, moonless nights can we see the outlines of its cloudy track of light across the heavens. More than any other celestial object it affects us with a sense of mystery and of unknown destiny — as, indeed, it has affected men at all times and in all countries. To the redman it was the "path of souls". In ancient mythology it had various meanings: thus, it was the highway of the gods to Olympus; or it sprang from the ears of corn dropped by Isis as she fled from her pursuer; or it marked the original course of the sun, which he later abandoned.

In medieval times it became associated by pilgrims with their own journeys. Thus, in Germany, it was the "Jakobstrasse", or the road to the shrine of St. James at Compostella; in England, it was the "Walsingham Way", associated with the pilgrimages to the famous Norfolk shrine of that name. There was nothing absurd or trivial in fancies of this kind; the pilgrim had no idea that his travels were the end and purpose of the Milky Way. He merely found it lying overhead, a mysterious path in the heavens; and his sense of universal unity led him in a childlike way to feel a deep association with it, and a sense of its intimate companionship. But this friendliness of the heavenly bodies, and the simple affection for them which we find in Chaucer and other medieval poets, have been destroyed for most of us by the mere interposition of unimaginable distances.

The best times for seeing the Milky Way are in the evenings of autumn and winter: it is then high in the heavens, and thus suffers less from the interference of our atmosphere. It is then seen to stretch like a vast, ragged semicircle over the sky. Indeed, it traces a rough circle, for this line is continued over the southern hemisphere also. The circle is, however, very far from being smooth or even; the path is full of irregularities. Its average width is about twenty degrees, but it varies considerably both in width and in brightness. Its total area has been estimated to cover rather less than one-fourth of the whole northern hemisphere of the sky, and to cover about one-third of the southern hemisphere. Its track lies through the constellations Cassiopeia, Perseus and Auriga; it passes between the feet of Gemini and the horns of Taurus, through Orion just above the giant's club, and through the neck and shoulder of Monoceros, here entering the southern hemisphere. It passes above Sirius into Argo and through Argo and the Southern Cross into Centaurus. Here it divides into two streams separated by a dark rift, in a manner which suggests the divided course of a river, around an island.

It is a very long island, however, for the double conformation of the Milky Way extends over one-third of its entire course — that is to say, one hundred and twenty degrees of the circle. The divergent branches reunite in the northern hemisphere in the constellation Cygnus. The brighter stream passes through Norma, Ara, Scorpio and Sagittarius; along the bow of Sagittarius into Antinous, here

entering the northern hemisphere again; then through Aquila, Sagitta and Vulpecula it arrives at Cygnus and reunites with the branch which left it in Centaur. From Cygnus the stream, now single, passes through Lacerta and the head of Cepheus to the point whence we started, in Cassiopeia.

As we follow the Milky Way throughout its course, we find it continually sending out streaming appendages of nebulous appearance towards clusters, nebulæ, or groups of stars. In Norma it sends out a complicated series of nebulous streaks and patches, covering the Scorpion's tail, spreading faintly over the leg of Ophiuchus, and extending beyond, as if to meet a corresponding branch sent off from the region of Cygnus in the northern hemisphere. The latter is a very bright and remarkable streak, running south through Cygnus and Aquila, to become lost in a dim and sparsely starred region. From Cassiopeia a vivid branch proceeds to the chief star of Perseus, and faint streaks appear to continue the "feeler" towards the Hyades and the Pleiades. There are many other feelers of the same kind, and they are all of great interest, because they seem to show some sort of influence exercised by the Milky Way upon the whole sidereal universe.

Proofs of the dominating position held by the Milky Way

But there are other indications, also, that the Galaxy holds a dominating position. For example, the Milky Way seems to determine very directly the groupings of various bodies in the heavens. The regions through which it passes are the exclusive habitat of certain classes, while other classes as consistently avoid it. Thus the gaseous nebulæ are almost all in or close to the path of the Milky Way, but the "white" or spiral nebulæ, on the contrary, congregate at a distance from it. Globular clusters, again, are found in very large numbers within it; in fact, a continuous line of star-clusters lies along its center for a considerable part of its course, forty out of about a hundred known clusters being within this zone. The open star-clusters, of which there are several hundred, are also in or near the galactic plane. This marked preference of clusters for the region of the Milky Way is worthy of notice, because of the suggested relation between globular clusters and the spiral nebulæ, which avoid that region. Red stars, gaseous stars, and short-period variables display also a preference for the region of the Galaxy.

Ancient and modern conceptions of the nature of the Milky Way

Strange theories as to the nature of the Milky Way have been advanced at various times. Anaxagoras thought it might be due to the shadow of our globe; Aristotle, that it was some kind of mist due to the exhalation of vapors from the earth.

But a grander and truer conception of its nature and situation, removed far from the earth and independent of any terrestrial cause, had early come to several minds. Pythagoras and Democritus both formed the conjecture that its shimmer might be due to innumerable stars, and in 1610 Galileo's telescope confirmed their theory.

As we have seen, the Milky Way is by no means a simple stream of stars; with careful observation, even the naked eye can perceive something of its irregular detail, when the atmosphere is unusually clear and there is no moon. Viewed under these conditions through a good telescope, the effect of the Milky Way, when made to pass progressively before the vision, is one of unexampled grandeur and sublimity.

The general effect has been well likened to that of an old, gnarled tree trunk, marked with knots and curving lines, and riddled with dark holes and passages, linked together by shimmering wisps or arches. This general effect is practically lost as the detail becomes clear in a telescopic view. The detail is extremely various. At one point it may consist of separate stars scattered irregularly upon a background of darkness; at another, of star-clusters, sometimes following one upon another in long, processional line; at another, the stars seem to collect in small, soft clouds, presenting the appearance, as the telescope sweeps over them, of drifting foam.

The strange, dark rifts in the skyscape where no stars appear

At yet another point the track may be involved in nebulosity in which many stars appear to be imbedded. Perhaps the most characteristic features are several which have already been remarked as conspicuous in star-clusters or nebulæ, such as lines of stars, dark lanes having the appearance of rifts, and more extended areas devoid of all light. The lines of stars, which are evidently connected by some actual physical relation, are either straight, curved, radiated or in parallels. In Sagittarius is a very striking collection of about thirty stars resembling in form a forked twig with a curved hook at the unforked end. The dark rifts in the Milky Way show the same features as those in star-clusters. Sometimes they are parallel; sometimes they radiate like branches from a common center; sometimes they are lined with bright stars; sometimes they are quite black, as if utterly void; sometimes slightly luminous, as if powdered with small stars.

Large, dark areas, resembling the Keyhole and other similar formations in nebulæ, are very frequent. The most famous of these is the Coal-sack, which occurs close to the constellation of the Southern Cross. Soon after the southern reunion of its two branches in Centaurus, the Milky Way broadens and appears studded with a collection of brilliant stars, so that this is one of the most resplendent areas in its whole course. Right in the center of this host of bright stars, and close to the four chief stars forming the Cross, is what appears to be a pear-shaped cavern blackly dark. This apparent opening into the great void is known as the Coal-sack. Many attempts have been made to explain away this phenomenon as an optical effect, but all these attempts seem quite inadequate. The sharp distinction of its outlines, its huge size, its utter darkness, and the even brightness of the starry edge surrounding it, make it almost certain that we have here a mass of obscuring matter cutting off the light of the stars behind it. It is by no means unique: there are a great many similar black areas, generally less clearly defined and less striking in appearance, but manifestly of similar nature. Barnard describes one of these, in Sagittarius, as "a most remarkable, small, inky-black hole in a crowded part of the Milky Way, about two minutes in diameter, slightly triangular, with a bright orange star on its north preceding (northwesterly) border, and a beautiful little cluster following". Here, again, a dark vacuity is found in conjunction with a number of bright stars.

Has some disintegrating force been at work in expanses of the heavens?

Another very striking irregularity is the Great Break in Argo, which occurs shortly after the Coal-sack. After its expansion in the Southern Cross the stream of the Milky Way narrows, but spreads out fan-wise in Argo; and here, at its widest part, it is cut sheer across by a dark irregular break. On either side of this Great Break the stream sends out finger-like branches of faint light, as if attempting to reach across, the branches on opposite sides of the Break being in obvious correlation. The appearance of a once-united stream rent asunder by some great force or by the intrusion of some foreign non-luminous body is very strongly suggested by this chasm; and, unless the apparent break is really due to intervening opaque matter, these dark rifts and chasms of the Milky Way, like those of star-clusters, point to the presence within this vast structure of some disintegrating force, which may eventually result in its entire dissolution.

The nebulous wisps and feelers which the Galaxy throws out towards stars, constellations or nebulæ are very interesting. Tenuous feelers of this kind reach, or very nearly reach, among others, the Hyades, the Pleiades, Præsepe, Orion's left shoulder and the Pole Star.

But a still more interesting fact has been discovered with regard to the relation of the Milky Way with all the other stars of the heavens. It is that, on the whole, the stars tend to increase in number gradually and in regular order toward the region of the Milky Way. According to Sir William

Herschel, the distribution of fairly bright stars is thirty times more dense in the galactic plane than at its poles. This law of galactic crowding has been traced further in remarkable detail by later investigators, and it has been found that a similar, though not numerically equal, crowding marks the distribution of the fainter stars also.

Is there a meaning in the crowding together of the most brilliant stars

This crowding is well exemplified, for instance, in the positions of the ten most brilliant northern stars. Three of these — Capella (in Auriga), Altair (in Aquila) and Deneb (in Cygnus) — stand almost upon the central line of the Milky Way; while four more — Vega (in Lyra), Procyon (the lesser Dog-Star), Betelgeux (in Orion) and Aldebaran (in Taurus) — are either just within or upon its borders. Only two out of the ten — Regulus and Arcturus — are at any considerable distance from the Milky Way. Yet, in proportion as the stars diminish in brilliance, their crowding toward the galactic zones becomes, for the stars visible to the naked eye, less and less marked, until it can barely be perceived in the case of those which are only just perceptible by unaided vision. In the first ranks of telescopic stars — that is to say, about the seventh magnitude — there is hardly any of this crowding, but in magnitudes below this it is again progressively evident.

Evidence of a general plan of construction in the heavens

This regular and conspicuous law is almost conclusive evidence of a general plan of construction in the heavens, in which the Milky Way is intimately involved and in some way dominant. A further proof of this dominance is supplied by the grouping of the nebulæ in the sky, for they form a striking contrast, or complement, to the grouping of the stars.

Two great zones in which spiral nebulæ are condensed are clearly apparent, and a map (see page 1553), showing both these areas and the path of the Milky Way, is very instructive. A large zone, with the Milky Way as its central line, is almost clear of nebulæ, which congregate as two great canopies hanging about the galactic poles. This accumulation of nebulæ towards the pole is particularly marked in the northern hemisphere; in the southern hemisphere, although the same principle prevails, there is less concentration, and the nebulæ appear more evenly dotted over the sky. The wide zone, which is avoided by spiral nebulæ, about the entire circle of the Milky Way, is very pronounced. Over gaseous nebulæ, on the contrary, the Milky Way exercises not a repellent but an attractive influence, just as it does over stars and star-clusters.

The curious avoidance of each other by stars and nebulæ

The study of the Milky Way emphasizes very strongly the "relation of avoidance" between stars and nebulæ. The apparent law, already well known to astronomers a century ago, was thus summed up by Herbert Spencer: "In that zone of celestial space where stars are excessively abundant, nebulæ are rare; while in the two opposite celestial spaces that are furthest removed from this zone, nebulæ are abundant. Scarcely any nebulæ lie near the galactic circle; and the great mass of them lie around the galactic poles. Can this be mere coincidence? When to the fact that the general mass of nebulæ are antithetical in position to the general mass of stars we add the fact that local regions of nebulæ are regions where stars are scarce, and the further fact that single nebulæ are habitually found in comparatively starless spots, does not the proof of a physical connection become overwhelming?"

The sublime constructive scheme that baffles human research

It is impossible to contemplate the vast system of the Milky Way, and the incontrovertible evidences of its intimate and far-reaching connection with the distribution of the heavenly bodies outside its own system, without speculating as to the nature of these relations, and as to their possible indication of some vast scheme of construction in the entire heavens. The

knowledge of stellar varieties, of the giants and dwarfs, of the violet-white Sirian and of solar stars and of all the other kinds, and our knowledge of the marvelous movements, variations and systemic relations of stars, expand and deepen the glory and mystery of the heavens. The sense of some vast, undiscovered plan comprehending the movements and relations of all is altogether in keeping with the sublimity with which the night sky impresses everyone. But when we review the attempts to construct this scheme we are baffled by a sense of their inadequacy and artificiality.

Rejected guesses at the architecture of the celestial temple

Sir William Herschel's "disc theory" was for many years generally accepted as a credible explanation of the distribution of the stars in the heavens. This theory had already been put forward, thirty years earlier, in 1750, by Thomas Wright, of Durham, but Herschel adopted and strengthened it by applying to it his method of "star-gaging". Starting from the hypothesis that the stars are actually, on a broad average, evenly distributed so that the distance between any two neighboring stars is the same throughout the space occupied by the system, he ascribed the appearances of concentration and of wide scattering to the varying depth or extent of the system as viewed from the earth; and was thus led to conceive of the heavens as a vast system of stars evenly distributed in a form roughly resembling a grindstone, the solar system being situated near the center, and the Milky Way representing an enormous depth of stars included in our view along the plane of the disc. The actual figure which Herschel deduced from his laborious plumbing of the star-depths was an irregular disc, cloven at one end, the cleavage representing the bifurcated part of the Milky Way.

But this theory requires quite incredible assumptions in order to explain such appearances as the Coal-sack and other features of the Milky Way. The Coal-sack and other black holes could only be explained by imagining vast conical tunnels through the whole stratum of stars, all converging directly upon the solar system, while stellar groups of exceptional richness would require for their explanation as optical effects the assumption of columns of stars of tremendous length stretching out from the edge of the disc away into space. Explanations of this kind are too fanciful. It is more satisfactory to accept the appearances as corresponding to reality, and to reject the hypothesis of the even distribution of all the stars.

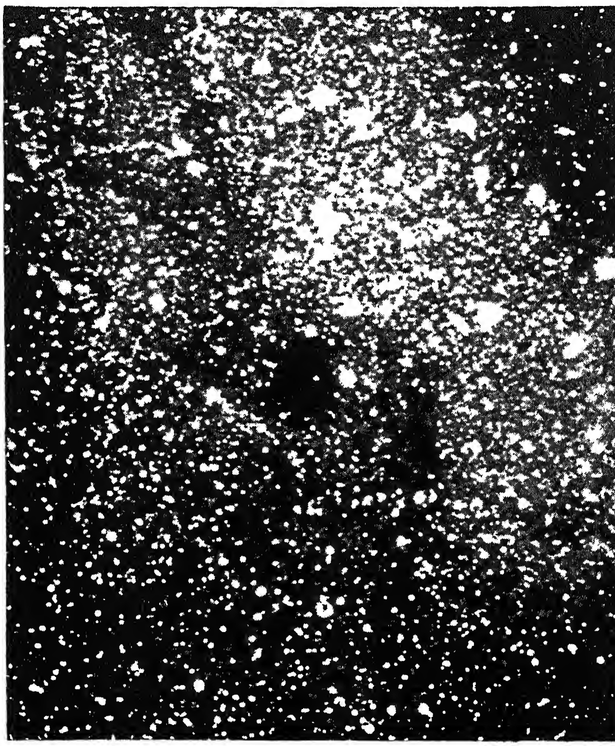
Indeed, Herschel himself came later to this conclusion, and rejected his own theory of a uniform disc-like sidereal system. The result of his star-gaging labors was eventually to demonstrate real inequalities of distribution. In 1802 he was able to say that "the Milky Way is by no means uniform. The stars of which it is composed are very unequally scattered, and show evident marks of clustering together into many separate allotments". Yet, notwithstanding this repudiation, the uniform-disc theory was for years afterwards accepted with all the authority of Herschel's name.

Sir John Herschel's theory little more adequate than his father's

Sir John Herschel, who continued to gage the star-depths in his father's manner, realized that the Milky Way must be a definite structure, and not a mere effect of perspective due to our position among the heavenly bodies. But he still conceived that the situation of our solar system was the most important factor in producing the appearances under which we see the Galaxy. He cut away, as it were, the center from the disc, and left the Milky Way as a flattened ring which we see edgewise from our position within its hollowed center. But this theory leaves almost all the difficulties intact. Appearances such as the Coal-sack and the Great Break in Argo require a similarly elaborate and artificial hypothesis to explain them under the conception of a ring as under that of a disc, if the ring be held to consist of evenly distributed stars seen in various positions and groupings, and looking thick simply because we regard the ring edgewise.

Any theory which regards the Milky Way as entirely or even chiefly an optical effect has to meet an insuperable difficulty in the definite outlines of the stream itself — at least over the larger part of its course. If the concentration of stars were an optical effect, it would almost inevitably be much more gradual, so that there would be no sharp limit to the Milky Way. But its outline is so well defined that in some parts one photographic plate may show one half within its borders and the other clearly without, thus including two regions of contrasted character.

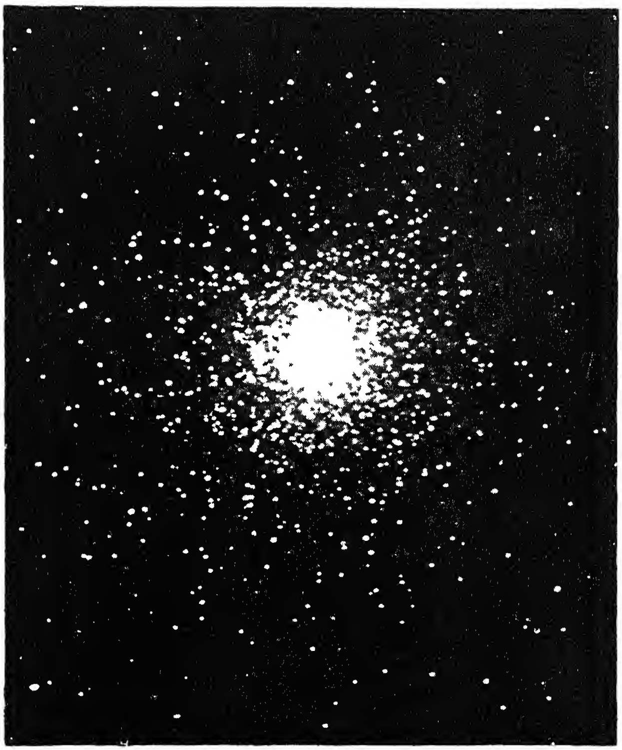
The wide prevalence of the principle of spirality throughout the whole range of heavenly bodies has led to various recent theories, which trace in the general conformation of the Milky Way double or quadruple spiral branches, so disposed to our view as to produce the effect of the stream which we have traced. About the middle of the last century a theory of this kind was brought forward by Stephen Alexander, of Princeton, who traced the origin of the celestial universe back to a great spheroidal mass subject to forces producing in it a spiral configuration, and saw in the Milky Way the surviving streams which issued from it, and flowed in four winding currents. The idea of the whole known universe as having originally been a single vast spheroid has been discredited by more recent discoveries of the extent and complexity of the sidereal system, but the theory that the Galaxy is itself a spiral structure similar to so many others which are revealed to us by modern instruments still finds many eminent astronomers to support it. And when to their characteristic structure we add the occurrence in the spiral nebulæ of clearly marked masses of occulting matter, the difficulties which the Coal-sack, the Great Break and other remarkable features of the Milky Way present to any other theory are very much lessened, if not entirely removed. Similar features characterize many of the great nebulæ, such as the black cavern of the Keyhole, the dark rifts of the Trifid nebula, and the lines or groups of bright stars, or single stars, significantly placed in relation to these dark areas. It is possible, however, to be too confident in attributing the appearance of the Milky Way to a vast spiral structure, because with increasing knowledge this starry stream may perhaps be explained on some other principle.



A STAR-CLOUD IN SAGITTARIUS, WITH A DARK ABYSS WITHIN IT, CONTAINING BUT A SINGLE STAR
From a photograph by E. E. Barnard.

In the meantime our knowledge of it is so incomplete that it is safest to regard the Milky Way as closely corresponding in structure with the appearance under which we see it. That is to say, it is probably a huge, irregular collection, somewhat in the shape of a watch or a grindstone, including within its vast system an endless variety of bodies and separate systems of stars, clusters and nebulæ, and throwing out branches and "feelers" in all directions,

over enormous distances, and controlling in some way the distribution of the various subordinate systems contained within it or associated with it. This influence of the Milky Way seems to be predominantly attractive for large aggregates of fairly dense matter, as in the case of the star-clusters, and predominantly repellent for masses of matter of low density or wide diffusion, as in the case of the spiral nebulæ; but any very detailed conjectures with regard to the nature of this varying influence are as yet premature. Progress in the study of the problem has been considerably hampered by the great difficulty in securing any definite knowledge of the dimensions of the sidereal universe and of the distances from us of the various parts of its complex structure.

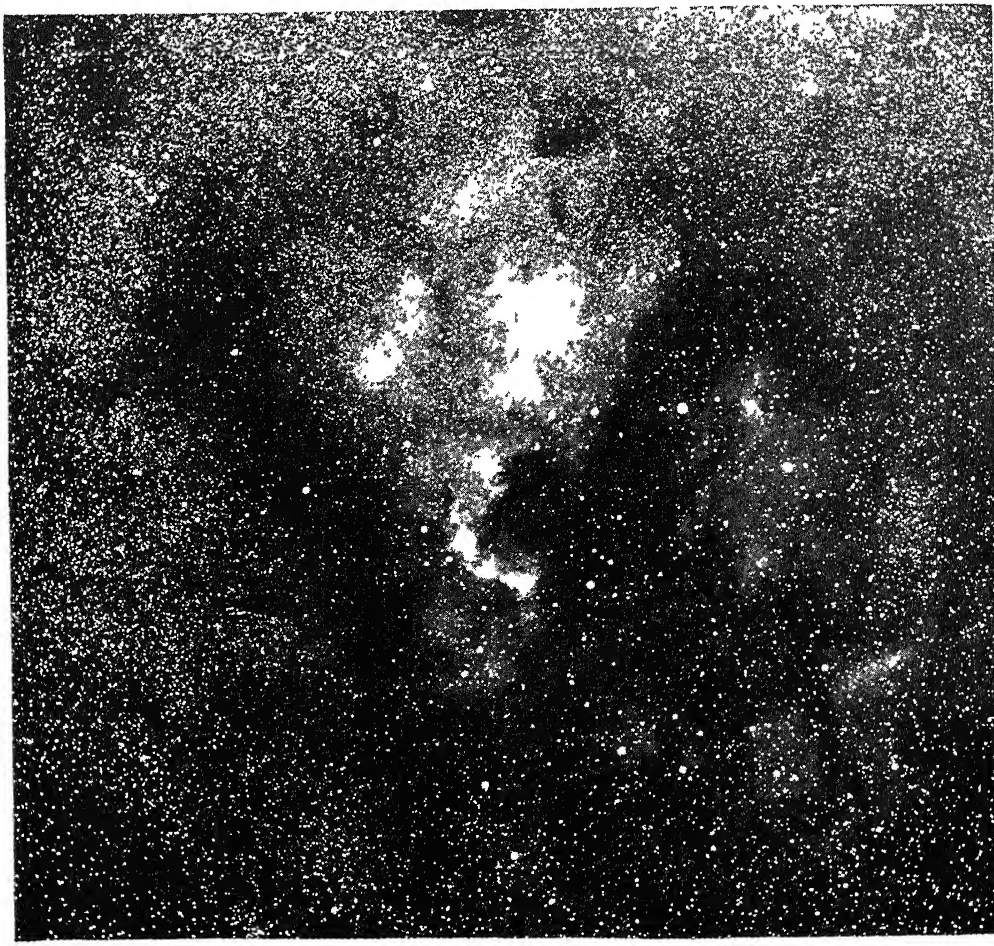


THE MAGNIFICENT STAR-CLUSTER MESSIER 13 IN HERCULES
From a photograph taken at the Lick Observatory.

Any attempt at making direct measurements of the distance from us of the star-clouds in the Milky Way results simply in showing that these clouds are immeasurably far away: none of the stars contained in them shows any perceptible parallax whatever and hence indirect methods must be followed in estimating their distance. The earlier estimates, made about half a century ago, aimed at establishing with some degree at least of probability the upper and lower limits of distance between which the clouds of the Galaxy must be: these estimates were based on an examination of the relative number of stars contained in the successive stellar groups differing from each other by one magnitude of brightness. If we assume magnitude to be, over a sufficiently wide average, a safe criterion of distance, we should expect to find the stars of each magnitude progressively more numerous than the stars of the next brighter magnitude. For as distance increases, with consequent diminution of brightness, so also does the available space increase; for the spaces at successive distances are contained within larger and larger spherical shells, with our own solar system as center. If, then, on a broad average, the stars are equally numerous at all distances, we should expect the number of stars of each magnitude to bear a regular ratio to the number of stars of the magnitude before it; and this ratio ought to be 3.98, or very closely four to one; that is, the number of stars of the seventh magnitude ought to be four times more numerous than those of the sixth magnitude, and so on. Now, from counts made of the stars listed in Argelander's great catalogue, known as the *Durchmusterung* and containing practically all the stars down to the ninth magnitude and most of those of the tenth magnitude also, it was found that from the first to the ninth magnitude the number of stars increased in fact in the given ratio, or rather in a ratio slightly inferior to it but sufficiently close to it to exclude the idea of any such addition of numbers as would result from the presence, within the sphere marked by the ninth magnitude, of the

host of stars contained in the Milky Way It was concluded therefore that the stars forming the Milky Way do not occur within the distance of the average ninth-magnitude stars This apparently gives us a lower limit to the possible distance of the main star clouds of the Galaxy.

The higher limit could not then be determined even with this broad degree of approximation, but yet from a consideration of Herschel's surveys which showed that the stars of the fourteenth magnitude were rather sparsely represented, it was concluded that the bulk of the galactic stars were situated at a lesser distance than that marked by the average fourteenth-magnitude star. Later counts made by Kapteyn, by Chapman and Melotte and by others, based on more complete catalogues and charts giving stars down to about the eighteenth magnitude, show that the ratio of the number of stars of successive magnitudes is, for all magnitudes, somewhat less than the theoretical value of 3 98 required on the supposition of equal distribution of stars at all distances from us, and moreover that this ratio falls off rather rapidly in the case of the fainter stars, being less than fifty per cent of the theoretical value for stars below the seventeenth magnitude.



NORTH AMERICA NEBULÆ
Photographed with the 10-inch Bruce telescope of the Yerkes Observatory by E E Barnard.

The fact of this thinning out of the stars below a certain magnitude, so clearly exhibited both by Herschel's soundings and by all the subsequent surveys, is of great interest and affords a very striking obser-

vational confirmation of the opinion that the sidereal universe though stupendously vast is not infinite but finite and limited. This conclusion is generally based on the argument that from an infinite universe of stars we should receive also an infinite amount of light, the increase in numbers making up at each successive step in remoteness, for the diminishing amount of light received from each star. The argument, of course, takes for granted the universal validity of the law that light does not suffer diminution as it travels through space — does not, so to speak,

BEAUTIFUL WISP OF NEBULOUS MATTER IN CYGNUS
From a photograph taken at the Yerkes Observatory

at last go out. If this law fails in any part of the universe, the darkness of the background of the sky cannot be taken as a positive proof of the limited number of the celestial host. But no evidence exists of the cessation of light due merely to its passage through space, however extended the journey may be.

The above considerations give us indeed some knowledge of the form of our sidereal universe and assure us of its finite extent; but they give no satisfactory knowledge of its actual numerical dimensions. More recent methods, based chiefly on the study of special types of variable stars and on the visual, photographic and spectrographic analysis of the structure of the globular clusters, have enabled astronomers to form a more definite estimate of the tremendous size of the complex system of which our own solar system, vast and complex as it seems to us, is but a minute element. The estimates formed by different scientists vary, it is true, very considerably but even the smallest estimates are almost overpowering when the mind first contemplates their significance. According to these lower estimates, the arguments for which have been ably summed up and defended by Dr. Heber Doust Curtis, Director of the Allegheny Observatory, the Galaxy is so vast that a pulse of light starting from one edge of the system would take from twenty to thirty thousand years to reach the other edge though traveling all the while with the unabating speed of 186,000 miles a second. If, however, we accept the figures of Dr. Harlow Shapley, Director of the Harvard College Observatory, and they are supported by very strong arguments and are being confirmed by new lines of research, we must still further tax our imagination and contemplate a system of stars and nebulæ and clusters the outer members of which are separated by such extreme distances that a pulse of light would take from two to three thousand centuries to complete its journey from one confine of the Milky Way to the other

And what shall we say of the hundreds of thousands of spiral nebulæ which seem excluded from the Galaxy and receding ever further and further away from us? Are they also parts of the same system situated at approximately the same great distances, as some suppose; or are they quite outside the galactic system, other "Island Universes" like unto our own but separated from us by distances a hundred times or more as great as that of the farthest stars in the Milky Way, yet bound to us by the slender thread of silver light that proclaims to us their far-off presence?

We now know that the "spiral nebulae" are not for the most part nebulae at all, but actually enormous systems of billions of stars much like our own Galaxy, or Milky Way System. We have examined with the photographic telescope hundreds of millions of these systems beyond our own, and have penetrated into space 500 million light-years in each direction, and this is probably only a mere beginning. The order and beauty and sublimity revealed even by our imperfect knowledge of the heavens exert an enduring attraction on the mind and will doubtless afford, until the end of time, an ever widening field for the exercise of man's ingenuity, courage and devotion in his ceaseless search for truth.

A HOME NURSING PRIMER

How to Care for Sick Members of the Family

Adapted from the Home Nursing Textbook of the American Red Cross by Its Technical Staff

IN spite of remarkable advances in the past few generations, only a small percentage of the persons who fall ill receive hospital treatment. As for the rest, they may be suffering from a mild illness, or the hospitals in their town may be overcrowded or they may live in a sparsely populated area where there are no hospitals. A trained nurse or, in some cases, a practical nurse provides good care for some of the sick people who are treated at home. But many other cases of illness are not serious enough to warrant the services of a professional nurse; besides, many families cannot meet the expense involved even if a case is serious.

At least one person in every family should have a certain amount of skill in home nursing. Usually this responsibility falls upon the mother; but the father or a younger member of the family may be called upon.

How to recognize symptoms

The home nurse should be able to recognize symptoms, or signs of illness, so that she may call the doctor without delay when his services are needed. There are certain clear symptoms, such as the color of the skin, rash, listlessness, cough and discharge from the nose or eyes. Other symptoms, such as pain, nausea, chilliness and dizziness, are noticeable only to the sick person himself. The severity of a symptom is not always a true guide to its importance; even a mild symptom that persists over a period of time may be a forerunner of a serious illness.

Babies and small children are not able to describe their feelings; we can only tell by their behavior when they are suffering pain or discomfort. To be sure, a listless or crying child may be only tired but if he also has a high temperature, he is sick and must be treated accordingly. Everyone—especially the home nurse—should be alert to symptoms of illness and should be able to describe them accurately to the doctor.

All photos and diagrams, American Red Cross

Taking the pulse and measuring the body temperature are helpful measures in diagnosing an illness.

General condition. Such signs of illness as lassitude, irritability or any unusual emotional reaction should be noted and reported to the doctor. If the patient has unmistakable symptoms, such as high temperature, the home nurse should put him to bed away from others in the house, even before she calls the doctor.

Body temperature. In some types of illness there is a disturbance of the heat-regulating mechanism of the body, and the body temperature may rise several degrees higher than usual or drop several degrees lower. These variations may be an excellent guide for the doctor in diagnosing the illness and also in judging its progress. Body temperature is measured by means of a clinical thermometer—a small hollow tube at one end of which is a bulb containing mercury. (See diagram on next page.)

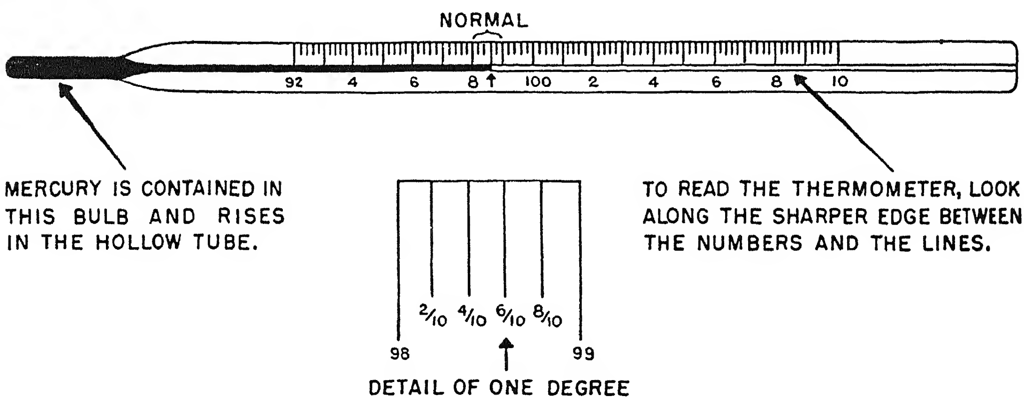
In the case of adults, the temperature is usually taken by mouth; it is taken by rectum in the case of babies, young children and, sometimes, the aged. The heat of the body causes the mercury in the bulb to expand and push up in the tube. The point at which the mercury stops indicates the temperature of the body at the time.

If the temperature is taken by mouth, a reading of 98.6° Fahrenheit indicates a state of health, although the temperature may vary at different times of the day or in different individuals. Slight variations are unimportant. If the mercury rises to a degree or more above the point marked normal (98.6°), we say that the person has a fever. The temperature taken by rectum is usually slightly higher than that taken by mouth; hence, the place where the reading was taken must always be recorded by the home nurse for the doctor's information. Some diseases are characterized by a high temperature, others by a low temperature; in still others, the temperature remains normal.

Readings should be taken once or twice a day as a matter of routine whenever a member of the family complains of feeling ill or whenever the home nurse observes symptoms of illness. When a doctor takes over the case, he may order more frequent taking of the temperature. Readings should not be taken within a half hour after the patient has swallowed food, drink or whatever medicines he is required to take.

Skin. The skin of the whole body should be observed for signs of swelling, rash or eruptions of any kind. Note whether the skin feels hot and dry or cool and moist, and whether there is an unusual amount of perspiration at any time. Reddened or discolored areas anywhere should be brought to the attention of the doctor.

Eyes. The eyes may seem heavy or unusually bright. Note whether there is any redness or discharge, or whether the eyes appear bloodshot or unusually sensitive to light. In some diseases vision is disturbed. The home nurse should report to the doctor if the patient complains of spots before the eyes, or if he is seeing double or if he cannot see objects clearly enough.



A clinical thermometer, used to measure body temperature. The heat of the body causes the mercury in the tube to expand and to push its way up; the point at which it stops indicates the temperature.

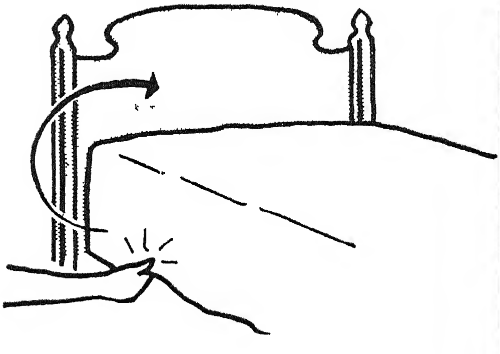
Mouth and throat. The mouth and throat should be inspected for redness, swelling and white or grayish spots or patches. The odor of the breath should be noted. To inspect the throat, hold the tongue in place with a tongue depresser or a spoon handle.

Nose. Difficulty in breathing and bleeding or other discharge of the nose should be noted. The discharge may be clear and watery, thick and yellowish or streaked with blood.

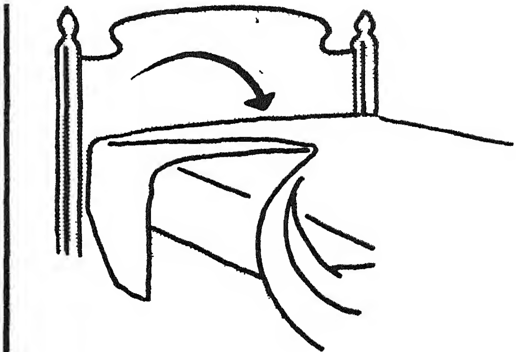
Digestive system. A digestive disturbance may be indicated by lack of appetite, nausea, vomiting or diarrhea.

Pain. Pain cannot be measured; therefore it is necessary to rely on the patient's description of it. The facts to be noted and

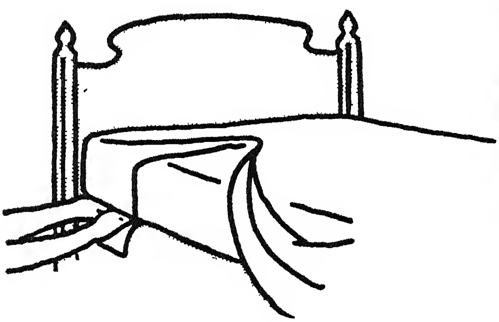
SNUG SHEETS ARE A BOON TO THE SICK



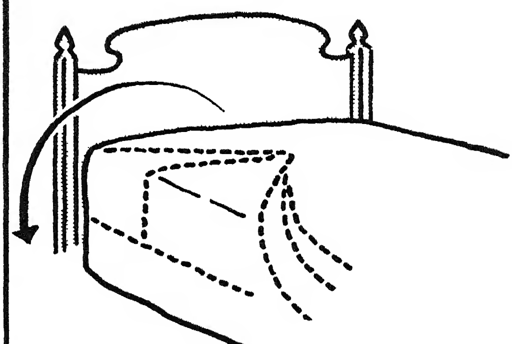
GRASP SHEET AS SHOWN ABOVE. RAISE...



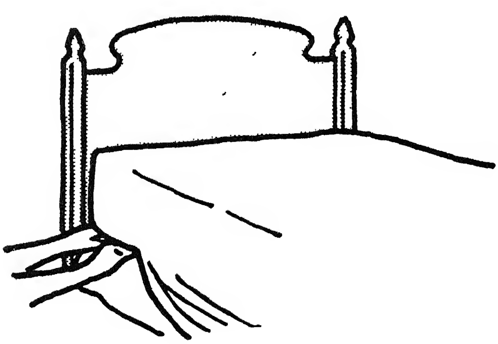
...AND LET FALL ON TOP OF MATTRESS.



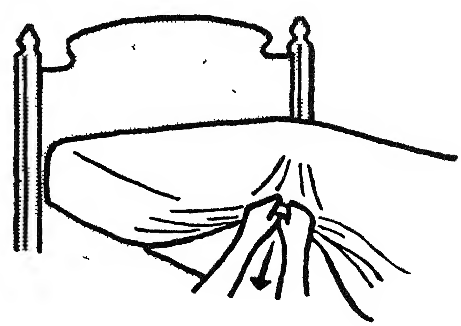
TUCK IN HANGING PART OF SHEET.



DROP UPPER CORNER OF SHEET.

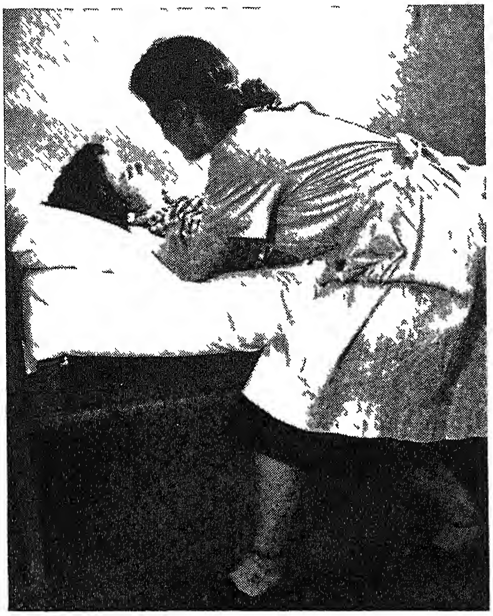


TUCK UNDER, BEING SURE TO CATCH FOLD COMING DOWN OVER HEAD OF MATTRESS.



WITH FISTS UPPERMOST, HANDS TOGETHER, PULL DIAGONALLY AND TUCK UNDER, HOLDING ON TO ROLL AS FAR AS IT WILL GO. REPEAT THIS ALONG ENTIRE LENGTH OF BED.

Steps in making a bed. There should be no wrinkles in the sheet, since these may chafe the patient.



Helping the patient to a sitting position in bed

Moving the patient to the near side of the bed

reported to the doctor are (1) the location of the pain, (2) the time when it was most severe, (3) whether it is increased or relieved by change of position, eating or drinking and (4) the patient's description of the pain as dull, sharp, stabbing, throbbing, slight or severe or continuous.

The home nurse should at all times be alert to anything unusual in appearance or behavior that might indicate illness or that might help the doctor to interpret the patient's progress.

How to keep the patient comfortable while he is in bed

The doctor nearly always orders a sick person to bed because the patient's body must have relief from activity while it builds up its defenses and makes its repairs. There are other reasons why those who are ill should be put to bed at once. Even if we cannot recognize a sick person's symptoms, there is always the chance that he may have contracted a serious illness. Again, if the patient has a communicable disease, he may infect other members of the family unless he is kept away from them.

It is desirable that a patient have a room by himself; it is absolutely necessary if he has a communicable disease. When a long illness is anticipated, all articles of furniture that are not actually needed should be removed from the room; only furniture that can be easily cleaned should be used. Necessary furniture for the sick room includes a comfortable bed, a small table, a chest of drawers and one or two chairs. Medicines and toilet articles should be covered with a clean towel to protect them from dust and to keep them from the view of the patient. Soiled dishes and linens should be taken from the room and placed where well people will not come in contact with them before they are properly cleaned. An atmosphere of harmony and cheer in the sick room has a soothing and beneficial effect.

A clean and comfortable bed is of vital importance. There should be a good thick mattress pad between the sheet and the mattress, both for the added comfort it gives and to protect the mattress from bodily discharges. Where there is likely to be vomiting, where the use of the bedpan will be required or where there will be drainage from wet dressings, the part of the bed most exposed should be protected by a rubber sheet or a piece of oilcloth

Rolling the patient onto his side in bed.

Rolling the patient onto his back in bed.

The bed should be snugly and smoothly made; there should be no wrinkles in the lower sheet. As a protection for the lower sheet and to avoid changing it too often, a drawsheet should be used. The drawsheet may be an ordinary sized sheet folded in half and placed across the upper part of the bed. It should be put on the bottom sheet, one edge should be well above the shoulders and the other well below the hips While the bedding over the patient should be tucked in well at the foot so it will not pull out easily, it should not be so tight that it is uncomfortable over the toes or prevents the feet from moving freely. A box-pleat may be folded into the bedding (lengthwise) before tucking it under the mattress, to give more fullness over the feet. Bear in mind that the patient should be provided with pillows for support The top cover on the bed should be light in weight while providing necessary warmth

How the home nurse should make the bed with the patient in it

Remove the top bedding, leaving one cover for comfort. Turn the patient away from you so that he will be lying on the other side of the bed; loosen the bottom sheet and push it toward the center of the bed so that it will be resting against the patient. Fold the fresh bottom sheet lengthwise and lay it on the mattress with the center fold in the middle of the bed and high enough to allow for tucking in at the top Make a square corner (pictures, page 2483) at the head of the bed; then tuck the sheet under the mattress, working along the side of the bed to the foot. Make another square corner at the foot of the bed, and tuck the sheet in at the foot.

Go to the opposite side of the bed. Roll the patient over so that he will be lying on the clean sheet. Pull the soiled sheet off the bed. Pull out the clean sheet over the rest of the bed; make square corners and tuck in as before. Replace the top covers, leaving toe space at the bottom of the bed by making a box toe pleat. When changing the pillow case, keep the pillow away from your face, since it has been near the patient's nose and throat discharges.

How to move the patient in bed

The home nurse will be able to work efficiently in moving the patient in bed if the bed is raised. Prepare four blocks of uniform height; bore a hole at the top of

each large enough to hold a leg of the bed Then set the legs in place in the holes of the blocks. To get the proper balance and leverage, the home nurse stands with one foot advanced in order to move easily toward and from the bed. Bend at the knees, keeping the back straight in order to avoid strain on the back muscles. Tell the patient what you are about to do so that he can co-operate with you. Loosen the covers on both sides. Help the patient flex his knees so that he can gain support by pushing his feet against the mattress. Move only on a prearranged signal so that he and you can move together.

Rolling the patient onto his side. Instruct the patient; loosen the covers; get the proper balance; have the patient flex his knees. Place one hand, palm down, over the patient's body and under his buttocks and the other hand under and across his shoulders. At a given signal pull him steadily toward you and gently roll him onto his side. Adjust his head, shoulders, hips, legs and feet for comfort.

Rolling the patient onto his back when he is lying on his side. Instruct the patient; loosen the covers; stand properly for balance and leverage. Place one hand on his shoulder and the other on his hip and on a given signal gently roll him back. Adjust his body for comfort.

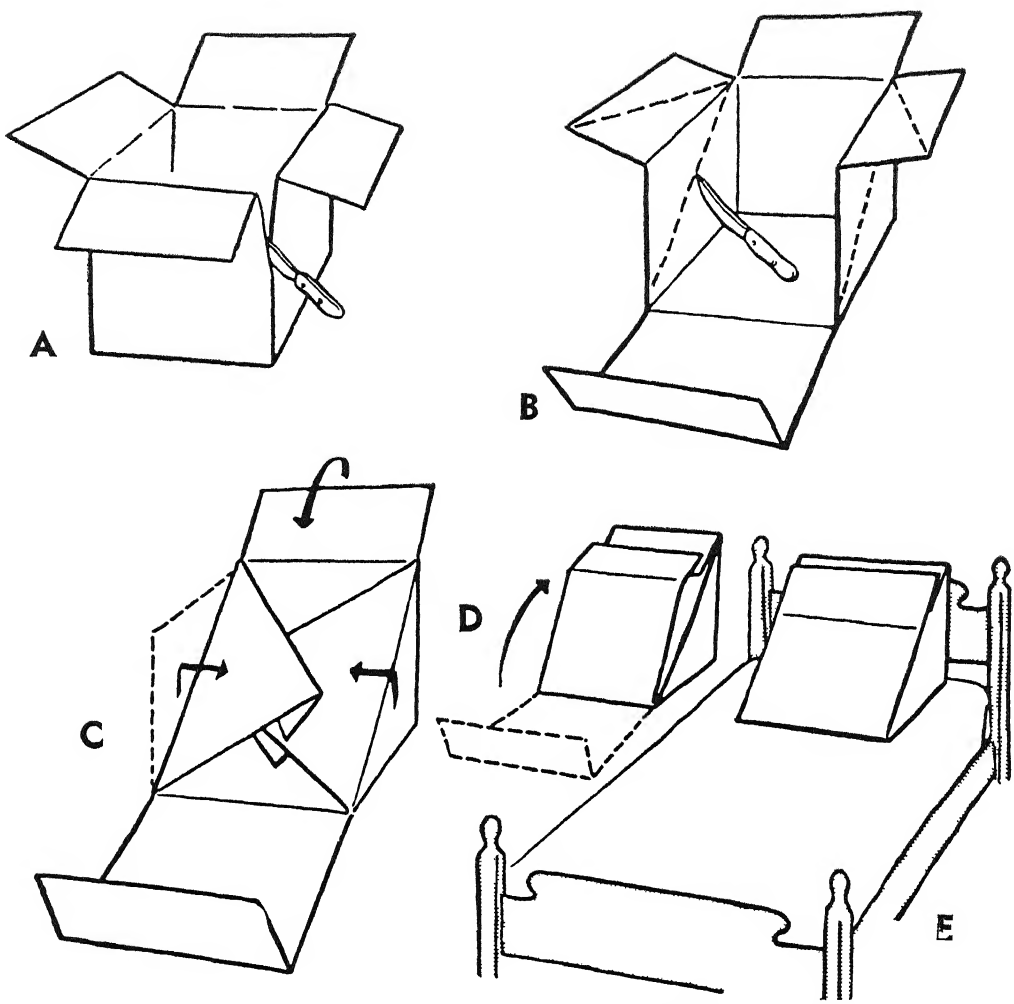
How to "palm" a wash cloth in order to prevent the wet ends from dragging across the patient's face.

Moving the patient from the center of the bed to either side. Get the proper balance. Help the patient to flex his knees so that he can push his feet against the mattress and help you move him. Place both arms and hands, palms up, under and well across the buttocks and on a prearranged signal pull slowly toward you. Then place both hands, palms up, under and well across the shoulders and pull toward you. Adjust the patient's body for comfort.

Raising the patient to a sitting position in bed. Help the patient to flex his knees. Bending at the hip, place one arm under the patient's shoulder and the other arm under his thighs; have him grasp your shoulder. When you are ready to lift, tell the patient to push with his feet, and raise him slowly to a sitting position. Pause until he is comfortable. Have him support himself by placing his hands behind him against the mattress. Lower him slowly the same way.

Moving the patient down toward the foot of the bed. Raise the patient to a sitting position; have him support himself with his hands at the back, keeping his knees flexed. Place one hand and arm under and well across the patient's thighs in front close to the buttocks, the other low at patient's back. Ask him to dig his hands against the mattress to help you and on a signal swing him toward the foot of the bed.

How to arrange a back rest. When the patient is well enough to sit up in bed he will need a back rest. Several types may be improvised from articles at hand with no expense. A straight chair may be placed bottom side up with its legs against the head of the bed so that its back forms an inclined plane; the chair may then be covered with pillows. A folded card table, washboard or bread board may be set on a slant, with one edge leaning against the head of the bed and the other resting on the bed in back of the patient; it should then be cov-



The above diagrams show how the home nurse can make a fine back rest from an ordinary paper carton.

ered with pillows. Overstuffed cushions from a chair or davenport may be encased in pillowslips and used for support when the patient sits up. Care must always be taken that the back rest is secure.

Perhaps the most satisfactory kind of back rest is one made from a paper carton, approximately 20 inches by 20 inches by 18 (diagrams on this page). Cut down along the edges of one of the short sides of the carton, as shown in A; this side will then lie flat (B). Then with a knife crease the two longer sides diagonally from the back top to the lower front (B); bend in at the crease, side flaps and all (C). Bend the flap down. Pull the front side over and up; make a crease and bend over any excess at the top (D). Tie your carton back rest with strong cord; then cover it with cloth to keep the bedding clean and for a neat appearance. Place the back rest with the slanting side toward the patient; put pillows on it for comfort.

How to give support and protection to a bony part. The bony parts of a patient in bed—his heel, his elbow or the end of his spine—may become tender because of continued pressure; the circulation may then become poor in that part and a pressure sore may develop. Keep the area clean and dry and give frequent gentle massage to stimulate circulation. Relief may also be

given and a sore prevented by placing a soft support—a "donut"—under the part. It may be made from absorbent cotton and gauze.

How to bathe the patient

Bathing is necessary in sickness no less than in health. The bath will refresh the patient; it will aid in the elimination of waste, such as perspiration and dead skin; it will stimulate circulation in the skin and it will also provide a mild form of exercise.

Principal points to keep in mind when giving a bath. Protect the patient by keeping him covered to avoid chilling, and keep the water comfortably warm; wash only small areas at one time. Provide support for the patient's body while bathing him so that he will be comfortable; use long, firm strokes in order to stimulate circulation and to give passive exercise. Select a time that is free from interruption and that is convenient for the patient and the household. The room should be comfortably warm and free from drafts. Collect and place at the bedside all the necessary equipment, including toilet articles, and work from one side of the bed in order to save energy. Wear an apron. The patient should be encouraged to do as much as possible for himself. In order to gain his co-operation, especially when it is necessary to move or lift him, tell him at each step what you are about to do.

Procedure for giving a bed bath. Wrap the wash cloth around your hand about mid-palm, anchoring the top under the thumb and tucking in the loose ends. This prevents dragging. Squeeze dry to prevent dripping. Bathe the face, supporting the head, first washing the eyes from the nose outward with clear water. Wash the forehead from the center to each side, using long, firm strokes and the flat of the hand; the cheeks from the bridge of the nose and up the cheek on each side; the upper lip, lower lip and under the chin with an S motion. If soap is used, rinse well, using the same motions, in order to remove all soap. Dry well, holding the towel so as to prevent dragging over the face.

Soap, rinse and dry the front of the neck and the ears, being sure to wash well in the creases and behind the ears. Continue in the following order: chest, abdomen, arms and hands, protecting the bedding and keeping the patient covered to avoid exposure and chilling. His hands may be kept immersed in the basin of water.

Turn the patient on his side to wash his back. Change the bath water at this time; as a matter of fact, it may be changed at any time when it becomes cool, dirty or soapy. Soap, rinse and dry, using long firm strokes, first washing the back of the neck and continuing down over the back of the buttocks. Before turning the patient, rub the back, using alcohol, powder or some lubricant on the hand, with long firm strokes in order to stimulate circulation and to give some passive exercise. Any reddened areas may be given extra rubbing.

Wash the legs and feet, covering the patient well and soaking the feet in a basin of water if desired.

Place the basin, wash cloth, soap and towel within the patient's reach and allow him to wash his genitals; place a towel under his buttocks to protect the bed. If the patient is helpless the nurse should finish the bath for the patient. Replace the gown and bedding.

Use of the bedpan

Warm the pan if necessary and sprinkle the seat with powder in order to avoid having the pan stick to the patient's skin. The seat may be padded if the patient is very thin. Protect the bedding with a bed pad. A serviceable bed pad may be made of about ten full sheets of newspaper, covered with cloth. Turn the bed covers back far enough to make it easy to place the pan. Keep the bedpan out of sight in a covered container when it is not in use; keep it covered when presenting it and after use. Cleanse the pan immediately after the patient has used it.

Placing the bedpan. Have the patient flex his knees; hold the bedpan in one hand by the side to slide it under the buttocks, open end toward the foot of the bed. Place the other hand under the small of the back; have the patient raise his buttocks on a signal and place them on the pan. Adjust the

An attractive tray, with its spotless cloth and its fresh flowers, whets a young patient's appetite.

pan for comfort. The patient may be placed in a sitting position if desired; have him support himself, or give him safe back support. Place a newspaper as an extra protection in front of the pan between the patient's knees. Allow him to use toilet tissues if he is able to do so. If he cannot cleanse himself, the nurse does this for him.

Removing the pan. Have the patient lie down and flex his knees. Place one hand under the small of the patient's back; raise him on a signal and with the other hand remove the pan carefully to avoid soiling the bed. Cover the patient at once and make him comfortable.

Cleansing the pan. Remove the pan; inspect the contents in order to make a report if necessary. Add cold water to keep the contents from sticking; use a swab (toilet paper, newspaper or other) to help remove any material adhering to the pan before emptying. Clean well with hot soapy water, using additional swabs as needed. Rinse well; dry the outside of the pan and replace it in its container.

The home nurse then washes her hands; the patient's hands should also be washed. The bed pad may be removed or left under the patient for further protection.

How to give medicine

Medicine should be given exactly as prescribed. The following procedure is recommended. Wash your hands, assemble all the needed materials, carefully read the label on the medicine bottle and check with the doctor's orders. Shake the bottle in order to mix the contents thoroughly; then remove the cork and place it topside down on the table to keep it clean. Hold the bottle with the label toward the palm and pour the medicine from the side opposite the label to avoid dampening or soiling it. It is important to keep the label dry and clean, because if it cannot be read, the directions cannot be followed accurately and the patient may be endangered. Measure the amount of medicine accurately according to the doctor's instructions, and read the label a second time as an extra

precaution against mistakes. After measuring the medicine, follow carefully any specific orders as to the addition of water or fruit juices. Present the medicine to the patient, giving him such help as is necessary; then wash the glass or spoon or other equipment with the greatest possible care and put it away.

The same precautions should be followed when giving drops, pills, tablets, capsules or powders. Pills, tablets and capsules should always be presented to the patient in a teaspoon and never from the nurse's fingers.

Medicines should be kept out of sight of the patient, in a safe place where children cannot reach them. When the patient recovers, left-over prescribed medicines should be destroyed by being thrown into the toilet or burned, unless the doctor advises otherwise. Many drugs grow stronger or deteriorate with age; they may be useless or dangerous if taken some months later. Under no circumstances should medicine prescribed for one patient be given to another, unless the doctor so orders. It is extremely dangerous to assume that the medicine which benefits one patient will be good for another under the same circumstances.

How to feed the patient

Feeding the sick is always an important part of medical treatment. While the doctor must decide what kind of diet the patient may have, it is the home nurse's duty to see that the food is so well prepared and served that the patient will want to eat it; that he has help, if necessary, in eating his food; that the doctor be kept informed about the patient's appetite and the effects of the diet, if any are apparent. In some cases the doctor will give specific instructions about what foods the patient may have; in others he may say that the patient should be kept on a liquid diet or a soft diet.

The home nurse must know what liquids provide the most nourishment and what foods are included in a soft diet. She must also know what foods will provide the necessary variety to give the patient a well-balanced and also entirely adequate diet. Liquid diet usually includes:

Fruit juices, strained.
Milk—whole, evaporated, malted, buttermilk.
Thin gruels, strained.
Soups, clear or creamed and strained.
Ice cream, plain.
Ices.
Cocoa or chocolate.

Milk may be prohibited under certain conditions, but if allowed, it provides more nourishment than any other liquid food. Fruit and vegetable juices are especially refreshing to the feverish patient and have good nutritive value. It is important to remember that many liquids are low in food value and for this reason the patient on a liquid diet must be fed much more often than when on solid foods. Unless the doctor orders otherwise, a glassful of liquid should be given every two or three hours.

Gradually, as the patient's condition improves, semisolid or soft foods may be permitted. Fruit juices, cereals and soups need no longer be strained; and light, easily digested foods are added to the diet. Soft diet usually includes all foods in the liquid diet plus:

Fruits, stewed and strained.
Cereals, well-cooked and sieved.
Bread, plain or toasted.
Soda crackers.
Eggs, poached or coddled.
Cheese, cottage.
Meats—scraped beef, white meat of chicken, fish.
Potatoes, baked or mashed.
Vegetables, cooked and sieved.
Gelatin desserts, plain.
Puddings, rice, bread, tapioca, cornstarch.

The meals of a sick person should be served regularly.

The appearance of the tray may affect the appetite favorably or unfavorably. Dishes should be attractive; the tray cloth and napkins should be spotless, whether they are paper or fine linen. The habit of placing a fresh flower or an interesting little favor on the tray makes mealtime some-

thing for the patient to look forward to with pleasure. Liquids or light refreshments should be served as carefully as the mealtime tray.

In preparing food for the patient, consider his likes and dislikes, but it is better not to ask him in advance what he wants to eat. The food should be served in small amounts, carefully placed on the dishes so that they will be neat in appearance. Hot food should be covered to keep it hot and cold food should be taken cold.

Before the tray is served, the patient should be allowed to use the bedpan, if desired. After this his face and hands should be washed so that he will feel relaxed and comfortable for his meal. The room and bed should then be put in order, the back rest and pillows adjusted to the patient's comfort and the bed table arranged conveniently.

Water is an essential part of the treatment of illness. If the patient is able to help himself, a pitcher or bottle of fresh cool water and a glass may be kept on a table beside him; otherwise water should be offered to him frequently whether he asks for it or not.

It is usually thought advisable for a sick person to take food in small amounts and for him to have light nourishment between meals, between breakfast and lunch and between lunch and supper. A glass of fruit juice or some other liquid will serve this purpose.

How to feed the helpless patient. When a helpless patient is being fed, the gown and pillows should always be protected with a towel or large napkin. If the patient is too ill to be propped in a sitting position with pillows, the nurse may place her hand under the pilllow, raise the head slightly and hold a glass to the lips. If the head cannot be raised or the patient prefers it, a drinking tube may be used. A glass drinking tube may be used, or a soda straw may be used for a drinking tube in an emergency.

If the patient must be fed with a spoon or a fork, the nurse should sit down by the bedside. She should not hurry the patient; he should have enough time to get his breath between swallows and to chew his food well.

Care of dishes from the sickroom. Flush all liquid waste down the toilet; place all solid matter in paper bags and burn, if possible. The dishes should be washed with hot soapy water; the rims of glasses and cups, the tines of forks and the bowls of spoons should be rubbed thoroughly, since these surfaces have come in direct contact with mouth secretions. Stack the dishes so that all surfaces are exposed, and rinse them with scalding water. Allow them to drain dry or use a clean towel. The dishes from any sickroom should be washed in this manner unless special instructions are given by the physician or public-health nurse.

Keeping a daily record

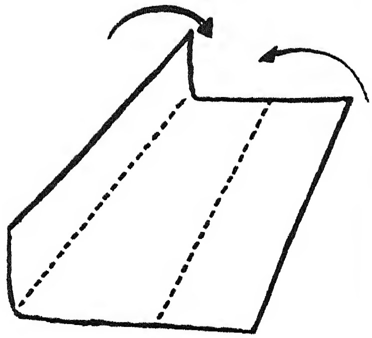
The doctor will find it very helpful if the home nurse can give him certain facts about the patient's condition, which changes from day to day. The home nurse should keep a written record, since it would not be safe to trust to her memory. The following form provides an easy way to keep such a record:

DAILY RECORD JANE JONES

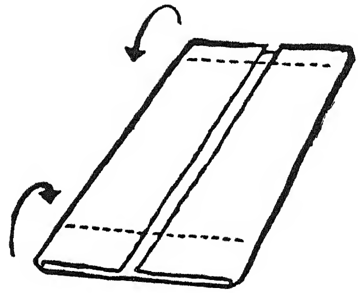
Date & Hour	Temp.	Diet, medicine, and treatments	U.	B.M.	Remarks

Note: U. stands for urination; B.M. for bowel movement.

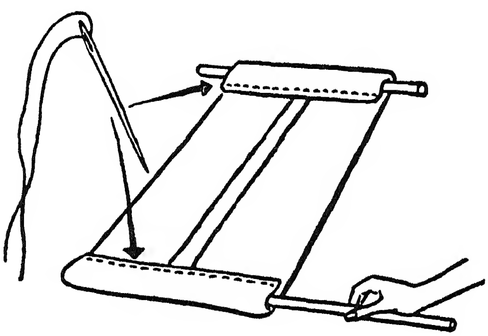
AN EFFECTIVE HOME-MADE WRINGER



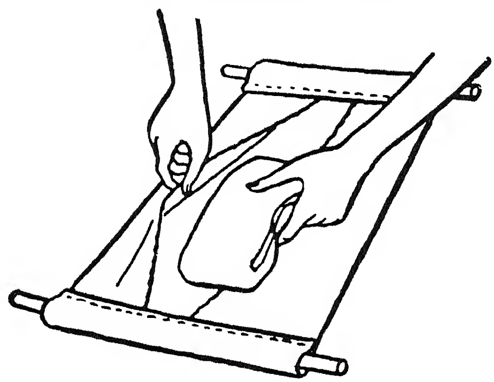
FOLD PIECE OF STOUT MATERIAL (SUCH AS TOWEL) LENGTHWISE.



THEN FOLD ENDS WHERE SHOWN BY DOTTED LINES.



STITCH ENDS AND INSERT STICKS IN LOOPS AT BOTH ENDS.



INSERT PIECE OF FLANNEL IN TOWEL.

POUR HOT WATER ON WRINGER OVER BASIN.

THEN WRING DRY BY PULLING APART AND TWISTING.

How to make a wringer out of stout cloth and two sticks and how to use it in preparing a compress.

The reverse side of the record sheet could be used to set down the doctor's orders and a variety of other useful data.

How to give simple treatments ordered by the doctor

Procedure for giving steam or vapor inhalation. Move the patient to the near side of the bed and cover his hair with a towel. Place a well-protected table, chair or stool in a convenient place near the patient. Make a tent of the bed covering or some similar material, using the head of the bed for a support; or an umbrella can be used to support the tent. Bring a steaming kettle or container to the bedside and place it on the table or stool. Adjust a funnel made of newspaper or a paper bag and direct it into the tent.

The water level in the kettle must be below the inside opening of the spout of the kettle in order to allow the steam to escape. If medication is ordered it may be placed in an open, weighted jar or can inside of the kettle, in order to avoid straining it. It will be necessary to add fresh boiling water to keep the steam up during the period ordered.

Stay with the patient continuously if there is any danger of the kettle's being tipped over. With small children it will be safer to remain at the bedside during the entire period of inhalation. When the inhalation is finished, dry the patient's face, remove the tent, adjust the bed clothes and put away the equipment.

When the patient is up and around, the inhalation may be given by using a paper bag. An opening should be cut in this paper bag to fit around the nose and mouth. Place the bag over the container of steaming water, which has been set on a tray or basin for safety.

How to fill a hot water bottle. The hot water bottle should be inspected to see that the washer is in place and that the stopper fits snugly. Test the temperature of the water before filling the bottle. The water should not be hot enough to burn the patient or damage the bottle; it should be just hot enough to be momentarily bearable to the fist of the person who is testing it.

Pour the water into the bottle slowly so that air may escape as the water enters. Fill the bag half full so that it will be light in weight and comfortable to the patient. Expel air by squeezing and pressing the bottle until there is water in the neck. Fasten the top so it will be tight; hold the bottle upside down to test for leaks. Dry the bag and cover it with a cloth or towel; then apply it as ordered, taking care that the patient does not lie on the hard neck of the bottle.

When the bottle is removed, empty it and hang it upside down to drain. When the bottle has dried, inflate it by blowing into it and then insert the stopper; if this is done, the sides will not stick together. If a hot water bottle is not available, a glass bottle or a warm flatiron can be used. When a glass bottle is employed, care must be taken to see that it does not break. No matter what sort of heat appliance is used, the home nurse must be sure that it is not hot enough to burn the patient. Particular care must be taken when heat is applied to a helpless patient.

How to fill an ice bag. Crush ice in pieces small enough to go into the mouth of the bag; a little water poured over the ice will remove sharp edges which may pierce the rubber. Fill the bag one-half to two-thirds full of ice to make it light in weight. To make the bag pliable, expel the air by laying the bag on the table and pressing gently until the ice comes to the mouth of the bag. Screw the cap on firmly and test for leakage. Dry the bag and cover it before applying. The bag should be removed for a short time every few hours to allow the blood to come back to the tissues so that they may be properly nourished.

After the ice bag is removed, allow it to dry thoroughly inside; then inflate it and replace the stopper so that the sides do not stick together.

How to prepare and apply a hot compress. A compress that is to cover a small area, such as a finger, may be wrung out inside of a towel. When a larger area is to be covered it is helpful to use a wringer made from a stout piece of material with

wooden sticks inserted in each end. (See the diagrams on page 2492.)

Assemble the compresses, wringer and basin near the boiling water. Place beside the patient a dry cloth (preferably wool), wax paper, cloth for the binder and safety pins, if necessary. Put a piece of flannel large enough to cover the affected area in a wringer over a basin. Pour boiling water over the flannel. Wring the compress dry by picking up the sticks at each end of the wringer and, holding it over the basin, twisting the sticks in opposite directions until the compress is as dry as it can be wrung. Take the compress to the bedside in a covered basin in order to keep it hot.

Remove the compress from the wringer, shake out the steam and apply gradually to the patient's skin, taking care to see that the compress is not too hot. Cover it with wax paper and flannel quickly, to keep the moisture and heat in. If necessary, pin a binder in place for security. Change the compresses as often as ordered by the doctor. Another compress should be ready to apply when one is removed. Take care to avoid chilling the sensitive skin while changing compresses. When the last compress has been removed, dry the skin and apply dry flannel over the area for comfort.

Taking the patient's temperature, pulse rate and respiration rate

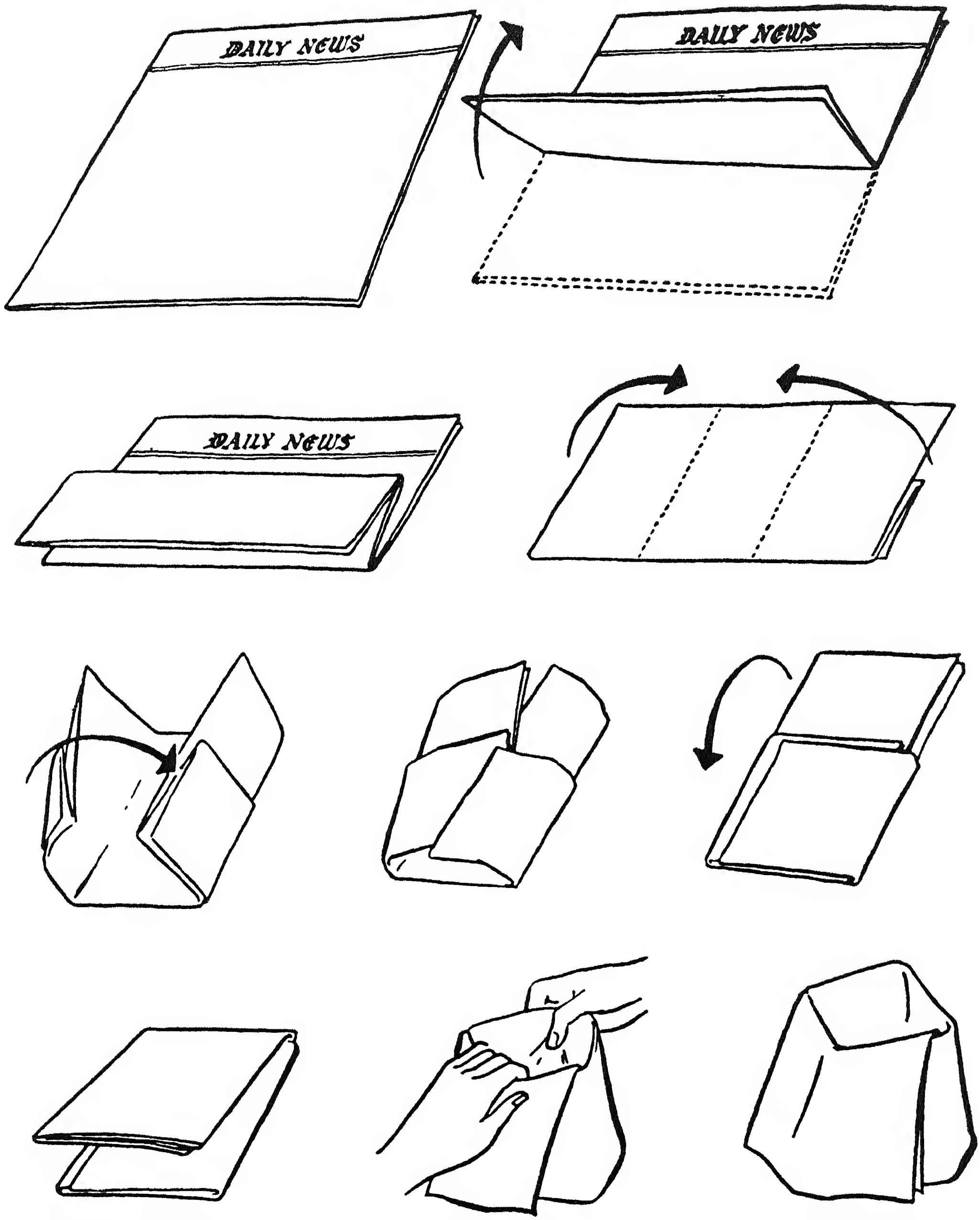
Procedure for taking temperature by mouth. Before you take the temperature your hands should be carefully washed. Grasp the thermometer firmly by the end opposite the bulb. (The bulb is the end containing the mercury reservoir.) With a quick snap of the wrist shake the mercury down below the 96° mark. Rinse the thermometer in cold running water to lubricate and then place the bulb in the patient's mouth, well under the tongue, and instruct him to keep the lips firmly closed. Let the thermometer remain in the mouth for three minutes; then remove it and wipe off the moisture with a piece of gauze or cleansing tissue, using a rotary motion from the end opposite the bulb down toward the bulb. Hold the thermometer horizontally in the right hand; locate the mercury by looking at the ridge between the numbers and the lines. Write down the reading on a piece of paper or on the patient's record.

After each taking of temperature the thermometer should be carefully cleansed. Hold the thermometer firmly by the tip with the bulb down. Wash it with cold water, soaking it well. Rub it with cotton, toilet tissue or facial tissue, getting well into the grooves and over the bulb; then discard the cotton or tissue. Rinse the thermometer with clear, cold water; repeat the soaping and rinsing. Dry the thermometer well so that it is both clean and dry before you put it back in the case. After taking the temperature and cleansing the thermometer, wash the hands with soap and water.

Procedure for taking temperature by rectum. The thermometer is lubricated with an oily substance for ease in inserting and for the comfort of the patient. Turn the patient on the side so that the home nurse can see the anus, which is the opening of the rectum, and insert the thermometer far enough to cover the bulb. Stay with the patient and hold the thermometer for three minutes. Cleanse the thermometer in the manner described above for cases in which the temperature of the patient is taken by mouth.

Taking armpit temperature. Axillary or armpit temperature is considered less accurate than temperature taken by mouth or rectum. It registers about one-half to one degree lower than mouth temperature; hence, when it is recorded it should always be followed by the letter "A" (axillary). To take armpit temperature, the thermometer and the armpit should be dry. Place the bulb of the thermometer in the hollow of the armpit. Fold the patient's arm closely over his chest, with his hand over the opposite shoulder, to hold the thermometer in place. Remove, read, record and cleanse as outlined for taking temperature by mouth or rectum.

Taking the pulse. Taking the patient's pulse is a method of counting the heartbeat. The rate, volume and rhythm of the pulse vary with individuals, with exercise and with illnesses. Generally, the pulse rate in-



A paper bag to hold soiled tissues, throat swabs and similar material can be made out of newspapers.

creases as fever rises. The normal rate is usually between 70 and 90 beats per minute. The pulse may be taken where large arteries come near the surface. The pulse at the wrist is the usual place. Have the patient lie or sit down and place his arm and hand in a relaxed position, thumb up, supported on a chair arm, table or bed. Locate the pulse by placing the forefinger on the thumb side of the patient's wrist between the tendons and the wrist bone. Count the pulse beats for one full minute; then check by counting for another minute.

Respiration. The breathing rate is

sometimes hard to measure because the patient is able to control it to some extent. There is a variation in the rate, volume and rhythm of respiration; it generally increases as fever rises. The normal rate is usually between 12 and 29 breaths per minute. Counting the respiration should be done unobtrusively; if the patient realizes what is going on, he may breathe more rapidly. If respiration is counted immediately after counting the pulse and while still holding the patient's wrist, it can usually be done without his knowledge.

Care of patients with communicable diseases

A disease that is carried from one person to another or from an animal to a person by means of germs is called an infectious or communicable disease. Most communicable diseases are caused by organisms that enter through body openings, particularly the nose and throat; but some disease-bearing organisms get into the body through a break in the skin or through the mucous membranes.

Disease-producing germs may be present in the mucous membranes of the nose and throat, or in the intestinal tract of healthy people; therefore we should all consider ourselves possible carriers of germs. Sick people are especially in need of protection, since their powers of resistance to germs have been weakened.

Hand washing. Since the hands are the greatest single offender in the spread of communicable disease, they must be kept scrupulously clean when nursing the sick. They should be washed before and after the care of the patient. This is done in order not to infect the patient, the home nurse or the other members of the family. Running water is preferable for hand washing; where it is not available, set up a hand-washing unit. This will consist of a pitcher of water, soap, a basin, towels and a pail for the disposal of dirty water.

Procedure for washing the hands. Wet and soap the hands, working up a good lather. Rub briskly, especially between the fingers and around the nails. Rinse the hands, keeping them lowered, so the dirt may run directly off the hands. This removes the outer layers of dirt and oil. Soap the hands again, working up a lather, again rubbing around the nails and between the fingers; rinse the hands, keeping them lowered until all soapy water has been washed off. Rinse off the bar of soap so that it may be clean for the next person. Dry the hands well. Wet skin or dried soap on the skin will cause chapping and roughening and may lead to possible infection.

Waste disposal. Another cause of infection is the careless handling of bodily waste and materials used in the care of the patient. All bodily discharges should be immediately flushed down the toilet. Soiled tissues or other material such as cotton pledgets (compresses) or throat swabs should be placed carefully in a paper bag and then taken from the room and disposed of by burning. Material that will be used again should be placed in a paper bag and carefully handled until laundered to prevent the spread of the infection. If paper bags are not available, a substitute bag can be fashioned readily from newspapers (see diagrams on page 2495).

When she nurses a patient with a communicable disease, the home nurse must realize that the care of the patient may be subject to the regulations established by the Board of Health. Sometimes the health officer or his representative visits the home to confirm the diagnosis of the case or to make arrangements for quarantine or isolation. In any event the doctor will give specific instructions as to the care of the patient with a communicable disease, and his directions should be carefully followed for the protection of the patient himself and for that of the family and the community.

It is impossible to learn all there is to know about home nursing by reading about it. The best results will be obtained by taking the home nursing courses offered by the American Red Cross and by other health or educational agencies. Courses of this sort provide expert instruction and also excellent opportunities for practice under supervision.

Science and Progress (1815-95) IV

by JUSTUS SCHIFFERES

INDUSTRY TAKES ROOT IN THE NINETEENTH CENTURY

SCIENCE was the soil in which modern industry took root. The spectacular advances in pure science in the nineteenth century gave rise to equally, if not more, impressive technological developments. These so quickly and directly affected the lives of men that many thought the nineteenth century marked the beginning of an age of limitless progress toward a veritable heaven on earth. Old industries grew and new ones arose as a result of the application of scientific discoveries to the needs and wants of mankind.

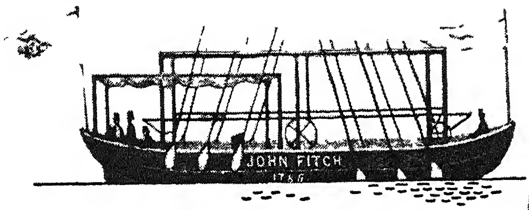
Among the most noteworthy advances in technology were those in transportation, communication, metal working and industrial and agricultural productivity. Let us begin with the transportation story.

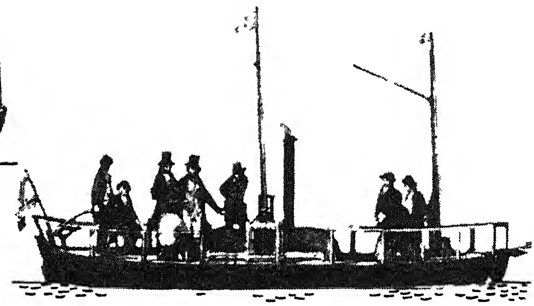
At the beginning of the century, passenger travel and the transport of goods by sea and land were slow, cumbersome and beset by many dangers. Seagoing ships — merchantmen and men-of-war — were markedly different in design from the galleons and caravels of previous ages, but they followed the same basic principles. They relied on the power of the winds applied to sails; when winds were contrary or when a calm befell, the vessel was practically helpless. On land, wheeled vehicles drawn by horses furnished the speediest mode of travel, but such travel was painfully slow by modern standards. Roads were generally abominable. Some persons chose to take their long journeys on horseback, since horses were not so greatly handicapped as coaches by poor roads.

The development of ships and land vehicles powered by steam brought about profound changes. There had been several attempts to propel boats by the force of steam before the nineteenth century. The Frenchman Denis Papin developed a steam-propelled vessel which, in 1707, sailed on the Fulda River, a tributary of the Elbe, under its own power; but the boat was destroyed by angry boatmen who feared for their livelihood. In the 1780's James Rumsey (1743–92), an American, built several steamboats. In a demonstration held at Shepherdstown, West Virginia, on December 3, 1787, before several hundred persons, one of these craft moved steadily along the Potomac River for two hours at the speed of three miles an hour. It operated on the jet-propulsion principle: steam, generated by a water-tube boiler, drove a pump that expelled a stream of water from the stern.

Another American, John Fitch (1743–98), fitted a group of paddles on each side of a vessel. The paddles, worked by steam power, were so arranged as to dip into the water vertically and to provide an upward, backward thrust. Later, Fitch converted the paddle wheels into a primitive kind of propeller. He established a steamboat service of sorts between Philadelphia and Trenton in 1790. But he received little encouragement and was constantly in financial straits. At last, in a fit of despondency, he took his own life.

William Symington (1763–1831), a Scottish engineer, further developed and improved the steam vessel. With the support of Lord Dundas, one of the proprietors of the Forth and Clyde Canal, he built the stern-wheeler Charlotte Dundas to tow barges on the canal. The Charlotte Dundas pulled two barges for a distance of





Above: steamboat built by John Fitch

Right "pleasure boat" of Symington

nearly twenty miles at the speed of three and a half miles per hour. But there was such an outcry about the "probable destruction" of the banks of the canal because of the "violent agitation of the water" produced by the paddle, that the project was abandoned.

The man who developed the first commercially successful steamboat was the American Robert Fulton (1765–1815). A talented painter, he visited Europe in search of instruction, like so many other budding artists of his time. While in England, he met James Watt and other noted inventors, and he began to devote himself to engineering study and experiments. He perfected a machine for twisting hemp into rope, but he was chiefly interested in creating new models of watercraft. He invented a submarine and won the backing of France and, later, of Great Britain for a time, but both governments ultimately decided that the submarine was not practical and withdrew their support.

With the backing of Robert R. Livingston, United States Minister to France, Fulton began to experiment in 1802 with a new type of steamboat on the River Seine. Returning to the United States, he built a steamboat with two side paddle wheels and named it the Clermont, after Livingston's country place. On August 17, 1807 — a red-letter day in the history of water transportation — the Clermont left New York, bound for Albany. Chugging sedately up the Hudson, the steamboat reached its destination thirty-two hours later.

Within a few years, stern-wheelers and side-wheelers were plying America's navigable waters. Soon steam power was used to propel ships crossing the Atlantic. In 1819, the American ship Savannah, using both steam and sails, made the trip from Savannah, Georgia, to Liverpool, England, in twenty-five days. The first vessel to cross the Atlantic using steam power all the way was the Canadian ship Royal William. In the year 1833, this coal-burning vessel completed a passage from Quebec to London in twenty-five days

The Swedish-born, naturalized American citizen John Ericsson (1803–89) helped inaugurate a new era in the history of steam-powered ships. In 1836 he invented the screw propeller, which ultimately was to be almost universally adopted. His revolutionary warship, the ironclad Monitor, built in 1861–62, opened the eyes of naval designers to the advantages of all-metal construction. More and more boats were built of iron and, later, of steel; the twin-screw propeller became popular.

An Atlantic crossing soon came to be reckoned not in weeks but in days. In 1891 the British ship Teutonic covered the 2,780 miles from Queenstown (now Cobh), Ireland, to New York in five days, sixteen hours and thirty-one minutes, a record that would have appeared fantastic at the beginning of the century. Of even greater importance than fast passenger service was the multiplication of slower but dependable freight steamers which, defying contrary winds and currents, could carry huge cargoes to the four corners of the globe.

The progress made in applying steam power to land transportation was equally spectacular. The great "industrial revolutionists" of the late eighteenth century, including James Watt himself, had realized the possibility of using the steam engine

N Y Histor Soc.

Robert Fulton and his ship — the Clermont.

to haul carts over tracks. An enterprising English engineer, Richard Trevithick (1771–1833), built the first steam locomotive in the British Isles as early as 1797. Seven years later, a Trevithick locomotive was used to pull a load of twenty tons on tracks originally set up for horse-drawn vehicles at the Pen-y-Darren collieries in Wales. Another Trevithick locomotive, hauling passenger coaches, was exhibited in London in 1808; but, strange as it may seem, this early train attracted little attention.

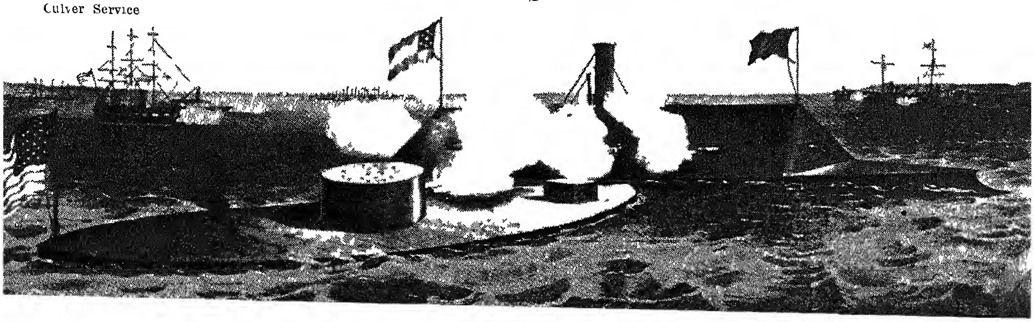
The first man to make the "traveling engine" a practical success was an English engineer, George Stephenson (1781–1848). His Rocket created a sensation in 1829 by speeding — at fifteen miles an hour — from Birmingham to Manchester, England, thereby winning a prize of £500 ($2,500). Soon the first regular railway passenger service was inaugurated by the Liverpool and Manchester Railway, and the enterprise proved to be exceedingly successful. Other passenger lines were now started not only in England but also upon the Continent of Europe and in North America. The railway era had begun!

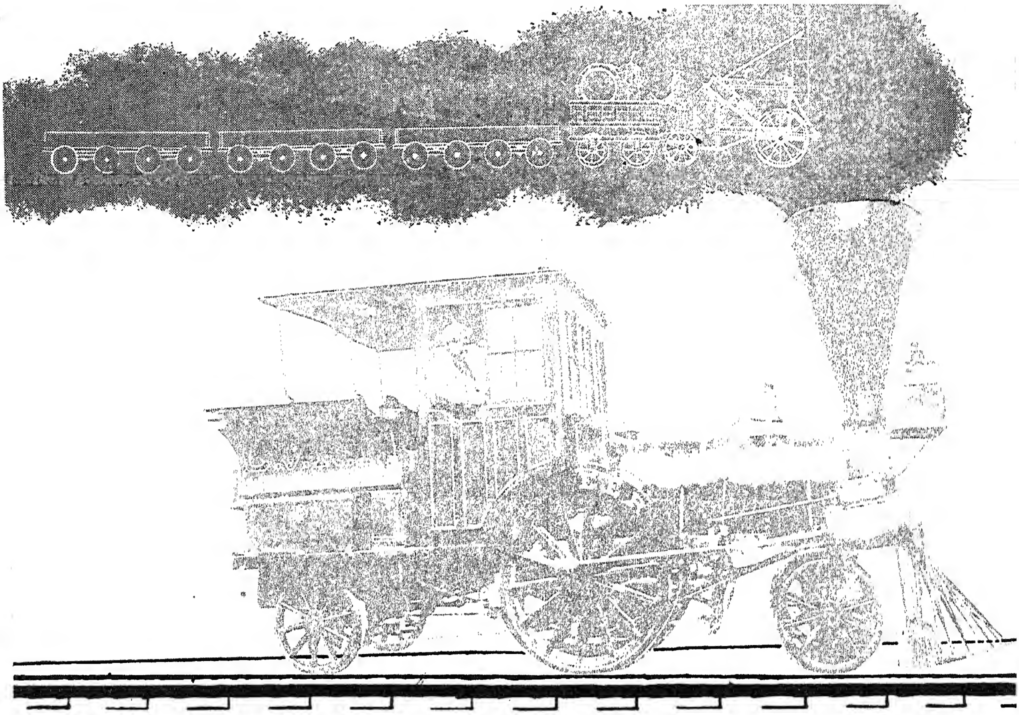
On Christmas Day, 1830, the steam locomotive Best Friend of Charleston, owned by the South Carolina Railroad, was put on the rails — the first locomotive placed in service on an American railroad. The first railroad *train* hauled by steam power ran from Albany to Schenectady, New York, on August 9, 1831. From that time on, the "iron horse" rapidly pawed its way across the American continent; by 1860 there were 30,000 miles of railroad in the United States. Before another decade had passed, a band of steel rails linked the Atlantic and Pacific coasts of the United States. On May 10, 1869, at Ogden, Utah, a gold spike was driven to commemorate the day on which the Union Pacific and the Central Pacific joined tracks. In 1900, 240,000 miles of railroad trackage crisscrossed the United States.

As we saw, Stephenson's Rocket traveled at a modest 15 miles an hour. In May 1893, the Empire State Express of the New York Central Railroad reached the trial speed of 112½ miles an hour — far greater than that attained in normally scheduled train runs today. Trains became safer too. In 1867, Thomas S. Hall invented the automatic electric

Battle between the Monitor and the Merrimac in Hampton Roads.

Culver Service



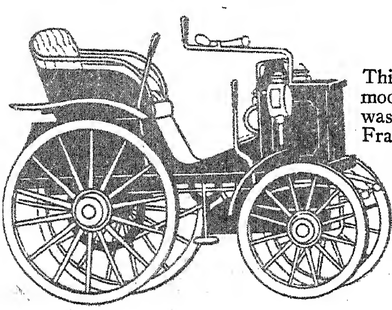


Pennsylvania Railroad

The photograph, above, is of the Pioneer, built in 1851 for the Cumberland Valley Railroad. The drawing shows Stephenson's Rocket.

block signal system; this warned the engineer of the presence of another train in the block, or section, of track just ahead of him. Another safety device was the air brake, invented by George Westinghouse (1846–1914); he began to manufacture his new invention in Pittsburgh in 1868. Westinghouse created many other safety devices for railroad safety, including the triple valve. He also entered the electric field, championing alternating current against Edison, who favored direct current.

The steam railroad was the most important new factor in land transportation in the nineteenth century, but other methods of land travel were inaugurated before the end of the century. The development of the electrical industry made possible the electric locomotive, the street railway and the subway. In 1888, Frank J. Sprague established an electric railway system in Richmond, Virginia. Electric-traction transportation proved to be an important factor in the phenomenal growth of American cities and suburbs in the latter years of the century.



This Paris-Rouen model automobile was popular in France in 1894.

The modern automobile also had its beginnings in the nineteenth century. Its immediate predecessor was the motorcycle. Before that came the bicycle, invented by the Scotchman Kirkpatrick MacMillan in 1840, developed in its modern form in 1876 by the English inventor H. J. Lawson and first marketed successfully by Starley and Sutton in England several years later. In 1885 a German inventor, Gottlieb Daimler (1834–1900), attached an internal-combustion engine (invented by Nikolaus August Otto in 1867) to a bicycle and thus produced the first motorcycle. The next step was the automobile, which harnessed the internal-combustion engine to a four-wheeled vehicle. We cannot say that any one person "invented" the automobile. Daimler helped develop it; so did the Frenchman Fernand Forest. In 1892, the first automobile to be built and operated

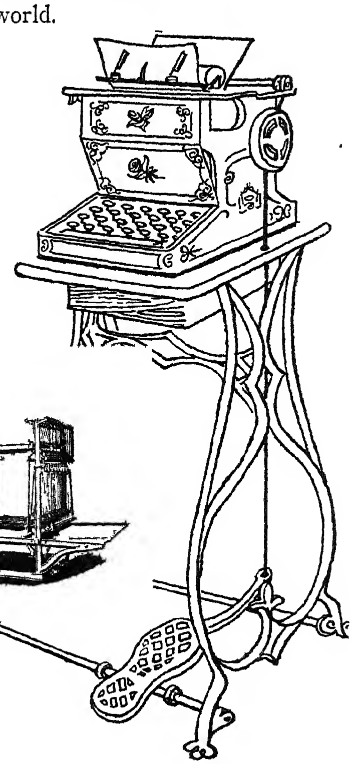
in the United States took to the road with its inventor, C. E. Duryea, at the wheel. Not so long thereafter, America was manufacturing millions of automobiles every year by means of mass production. The automobile assembly line, with a finished vehicle driven off every minute or so, is typical of the *flow of materials* on which, along with standardized parts, modern mass production rests.

There was also immense technological progress in the nineteenth century in the field of communication. We have already discussed in a previous chapter the beginnings of the telegraph and the telephone, which made possible almost instantaneous communication. (See Science and Progress II, in Volume 5.)

There were other outstanding developments in communication. The art of printing, for one thing, was completely revolutionized. The invention of the rotary press by Richard Hoe in 1846 greatly speeded up press work; his Lightning Press could turn out 2,000 small newspapers in an hour. The halftone engraving process (see the chapter The Graphic Arts in Volume 1) was invented in 1886 by Connecticut-born Frederick Eugene Ives; it marked a new era in the illustration of books and newspapers. Perhaps the greatest single innovation in the art of printing since the time of Gutenberg was the Linotype machine. With this an operator sets complete lines of type, immediately cast in lead, by pressing various keys on a keyboard.

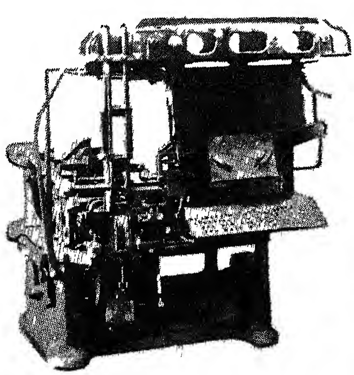
The inventor of the Linotype was Ottmar Mergenthaler (1854–99), a German-born naturalized American citizen. After he had obtained a patent on the machine in 1884, he found it difficult to get printers to use it. At last, however, a great metropolitan newspaper, the New York TRIBUNE, installed Linotype machines; and soon they were widely adopted. (THE BOOK OF POPULAR SCIENCE has been set in type on Linotype machines.)

The first commercially successful typewriter was developed in 1868 by the Americans Christopher Latham Sholes, Carlos Glidden and Samuel W. Soulé. The machine was put on the market as the Sholes and Glidden typewriter. In 1873, the rights to the typewriter were sold to the Remington Arms Company for $12,000. The great American humorist Mark Twain was one of the first users of the machine, and he was delighted with it. Said he: "It prints an awful stack of words on one page. It doesn't muss things or scatter ink blots around." The typewriter speeded up business operations tremendously. It was one of the early factors in introducing women into the business world.



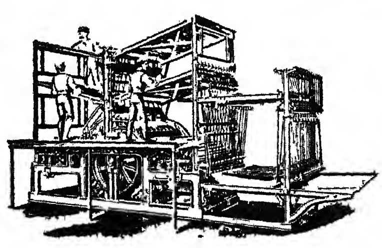
"Sewing machine model" typewriter.

Remington Rand



Mergenthaler Linotype Co.

Early Linotype machine.



R. Hoe and Co

An old rotary press.

In an old photographic studio. In the early days of photography, poses were apt to be stiff and formal.

The nineteenth century saw the birth of one of the principal modern arts of communication — photography. Based upon the effect of light upon certain sensitized substances — especially silver salts — it was first developed in France by Joseph Nicéphore Niepce and Louis-Jacques-Mandé Daguerre. The daguerreotype process, introduced by Daguerre, was very popular for a time; in it, a sensitized copper plate was exposed to light, was developed and became the finished photograph. At about the same time an Englishman, William Henry Fox Talbot, developed the process known as calotype or Talbotype. It was Talbot who produced the first negative (on paper); this could make many prints of a single photograph.

The methods devised by Niepce, Daguerre and Talbot were replaced by the wet-plate process. In this, a glass plate was made light-sensitive by coating it with collodion and plunging it into a solution of silver nitrate. After it was exposed, the plate was developed and yielded a negative. Many fine photographs were made by experts using the wet-plate process, but the method was cumbersome and inconvenient and was ultimately replaced by the dry-plate process. The introduction of flexible film by George Eastman marked another milepost. This film could be easily fitted into any camera and could be just as easily removed. The number of amateur photographers now increased by leaps and bounds, and the photography industry soon became big business. Incidentally, the use of flexible film made possible the development of motion pictures.

The advances in transportation and communication had far-reaching effects. Progress in transportation made it possible to bring in raw materials for industry from the four corners of the earth and to send them out again in the form of finished products, all this in a fraction of the time required in other centuries. It made more and more of the little-known or uncharted areas of the world accessible to mankind. Progress in communication brought scientists, industrialists and businessmen of every land into more intimate contact; it brought the benefits of education to millions. National boundaries began to shrink; the nations began to draw closer together. Men began to cherish the dream of "one world" — a concept that was to grip the imagination of mankind after each

of the two world wars of the twentieth century.

Technological progress was triumphant in many other fields in the nineteenth century. As machine tools increased in efficiency (see page 1313), they turned out a vast array of new machines for the manufactures of the world: textile machinery, turbines, blowers, trip hammers, compressed-air machines, electric devices. New machines like the typewriter, just described, and the mechanical calculator, or adding machine, were introduced into the business world; the work of the homemaker was lightened by ingenious contrivances like safety pins, friction matches and the sewing machine, perfected by Elias Howe.

Farm machinery represented one of the supreme triumphs of nineteenth-century technology. For a time, at least, it seemed destined to solve the problem of providing food for the earth's teeming millions, thus setting at naught the prophecies of Thomas Malthus (see page 1675).

In 1833 the inventive Maine farmer Obed Hussey (1792–1860) obtained a patent for a reaping machine that really worked. Another type of reaper was patented in the following year by Cyrus Hall McCormick (1809–84) and his father. Beginning the manufacture of reaping machines in Chicago in 1847, McCormick and his brother, Leander James, built a quarter of a million of these machines in the next twenty years. Constant improvements were made on the reaper in the years that followed. By 1888 the McCormick combine, a huge machine consisting of a reaper and thresher and drawn by twenty to forty horses, could clean up from seventy to eighty acres a day.

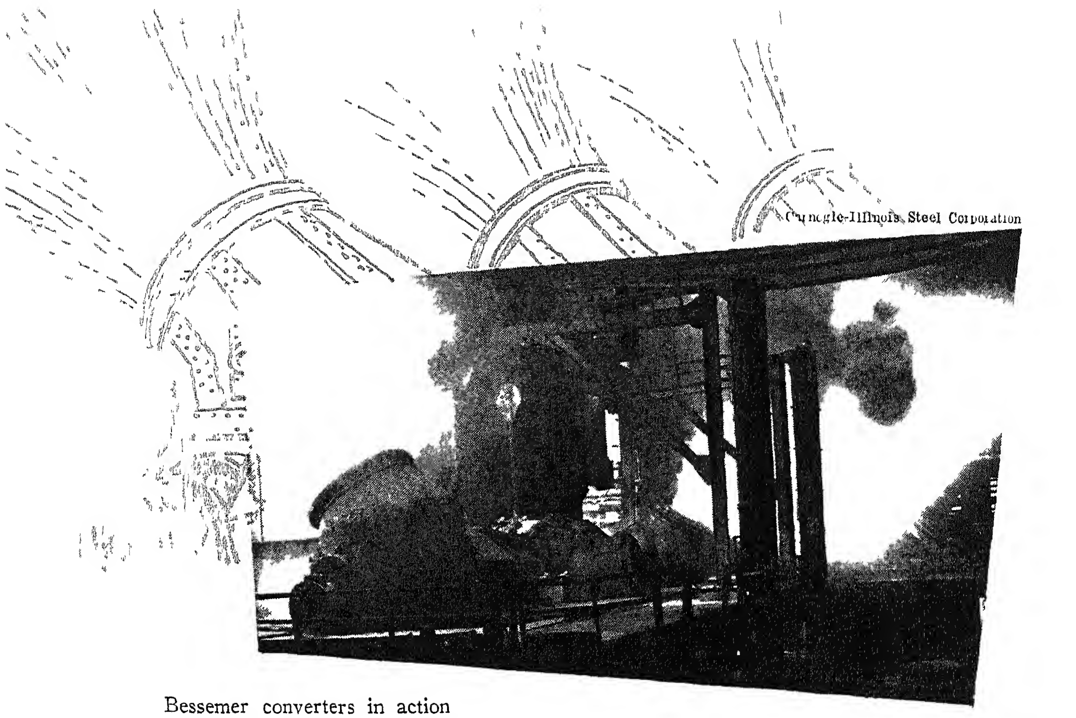
Vastly improved plows, harrows and seeders were developed. In 1830, it took a farmer more than half an hour to plow, harrow and seed enough ground to produce a bushel of wheat. In 1900, a farmer could complete the same task in just about two minutes.

The increasing use of machinery brought about an ever increasing demand for metals. Iron and steel (which is an alloy of iron) have been particularly basic in the development of industry. The smelting of iron is an ancient art, familiar to the Egyptians and to the secret guilds of ironmakers who lived on the wind-swept mountain slopes of Armenia as far back as Biblical times. Steelmaking also goes back to antiquity; the Greeks worked and hardened steel at least a thousand years before the birth of Christ.

In modern times the first notable improvements in steelmaking were achieved in Sweden and England in the eighteenth century. Christopher Polhem (1661–1751), a Swedish clerk turned engineer, worked his iron masses under rollers and hammers powered by crude steam engines; as a result Swedish steel, for the time being at least, became the best in the world. Another notable advance was the puddling process, developed about 1784 by the English ironmaster Henry Cort (1740–1800). In puddling, pasty masses of molten iron are puddled, or stirred, with iron bars; the ore is then removed in lumps, which are later hammered into a solid "bloom."

Discovery of rich deposits of iron ore

The industrial age could not be truly achieved until new supplies of raw material and new processes of steelmaking became available. Both these things happened about the middle of the nineteenth century. At that time unbelievably rich deposits of iron ore were discovered in the Lake Superior region of the United States. This ore could be transported quickly and easily by way of the Great Lakes and the Soo Canal to the eastern coal fields. (Coal is essential in the smelting process.) The first iron mines in the Lake Superior region were developed in upper Michigan. In 1870 a railroad surveyor found a new source of iron ore in Western Minnesota, in the Vermilion Range. Twenty years later, the Merritt brothers of Duluth found huge deposits in the Mesabi Range, seventy-five miles west of their home town. This was one of the richest iron-ore strikes of all time. The deposits lay close to the surface, so that the ore could be extracted



Carnegie-Illinois Steel Corporation

Bessemer converters in action

by the simplest of methods — strip mining, which consists of digging away the surface of the earth in order to get at the ore that lies beneath. (The steam shovel was invented for this purpose.) In the second half of the century, too, the iron deposits along the border of France and Germany and extending into Luxembourg and Belgium began to be more vigorously exploited than ever before. All these developments made vast stores of iron ore available to mankind.

The new steelmaking processes of the nineteenth century resulted to a great extent from the increasing knowledge of the chemistry of steel. This had been almost completely unknown to the hit-and-miss ironmasters of the eighteenth and early nineteenth centuries. They thought, for example, that sulfur was a valuable impurity in iron; actually, it is a serious detriment. As a matter of fact, the most serious problem in making steel is to get the impurities out of iron before carbon and other materials are added to it.

About 1856 an Englishman, Henry Bessemer (1813–98), and an American, William Kelly (1811–88), devised a method of removing impurities from iron. They invented, independently, what is popularly known as the Bessemer process; it is more accurately called the Bessemer-Kelly process Molten iron ore is poured into a pear-shaped, tilting crucible, called a converter; then blasts of air are forced through the crucible. Flames thirty or forty feet high shoot out of the mouth of the crucible as the impurities are burned out. When they are gone, the flames subside. Into the crucible then go measured amounts of carbon and other ingredients, and the crucible is tilted to let the steel run into molds.

In 1870 a still better process of making steel was developed in the United States — the production of steel by the open-hearth furnace, introduced by Edward Cooper and Abram Stevens Hewitt. In the open-hearth method, large rectangular furnaces are used. The furnace is loaded with pig iron, steel, scrap, unrefined iron ore and limestone, and the charge is brought to a molten state. Slag forms at the top of the molten mass and molten steel at the bottom. Both the slag and the molten steel are run off at intervals. The steel is poured into ingot molds and solidifies in the form of ingots.

The United States soon reached the front rank as a producer of steel. In

1850, all the furnaces in the country made only half a million tons of pig iron and practically no steel. Fifty years later, the United States was preparing as much pig iron and steel as England and Germany combined and was responsible for about a third of the world production. During World War II, when America was the "arsenal of democracy," its steelmakers produced more than 90,000,000 tons of pig iron and steel a year.

Many other metals besides iron and steel became available to industry in great quantities because of new technological developments. For example, aluminum was converted from an unimportant and expensive metal, used almost exclusively for jewelry and novelties, to one of the basic materials of industry. It was in the year 1886 that Charles Martin Hall (1863–1914), a young American chemist at Oberlin College in Ohio, developed a new method for producing aluminum. He had discovered that aluminum oxide could be dissolved in molten cryolite and that, when an electric current was passed through the dissolved oxide, pure aluminum could be extracted. The same process was discovered almost simultaneously by Paul-Louis-Toussaint Héroult (1863–1914), in France. The Hall-Héroult process, as it came to be known, caused a spectacular drop in the price of aluminum. In time the metal came to be used for almost every conceivable purpose, from the manufacture of cooking utensils to airplane and building construction.

More and more chemicals were required as industry waxed and prospered. Sulfuric acid had to be prepared in vast quantities for the manufacture of other chemicals and for fertilizers. Nitric acid was needed for explosives and also for the dye industry; sodium sulfate for the glass and paper industries; caustic soda for the manufacture of paper and soap. A huge chemical industry arose in order to provide all these chemicals and many others. In the last decades of the century, industrial chemists also began to manufacture synthetic products derived from the compounds of carbon (organic compounds)

Strictly speaking, the term "chemical industry" applies not only to the industries that manufacture chemicals but to all those that transform raw materials into products that are chemically different. Thus, the glass industry is, technically speaking, a chemical industry, because the finished product — a glass bottle, say — is composed of wholly different chemical compounds from the sand, soda and other ingredients that furnish its starting point From this viewpoint, the tanning industry is a chemical industry; so is the paint industry; so is the rubber industry; so is the petroleum industry. They have all benefited enormously by the advances in chemical know-how developed in the nineteenth century.

The application of science to technology, in that century, brought about a higher standard of living for millions of people — and populations began rapidly to increase. It also led to still greater achievements in the twentieth century.

NEW KNOWLEDGE OF THE HEAVENLY BODIES

The nineteenth century was as truly an age of progress in the field of astronomy as it was in chemistry and physics. Astronomers, during the long night hours, amassed countless thousands of observations on the stars, planets, comets, asteroids and other heavenly bodies. Efficient and powerful telescopes replaced the awkward, colossal instruments of the eighteenth century. Intricate and complicated instruments were invented to pierce the secrets of the universe. Observatories sprang up all over the world. Astronomers pulled the loose ends of their science together; they learned new ways of thinking about the earth and its neighbors in the sky.

Most of the discoveries of the century, however, exciting as they were to the astronomer, did not seem so dramatic to the layman as some of the spectacular feats of other centuries. There was, for instance, little in the nineteenth century to compare

in drama with Galileo's discoveries made at the beginning of the seventeenth century with his tiny "optik tube." Nor was there anything that could be compared with the popular excitement in the twentieth century over the most intensely dramatic of all scientific triumphs — the splitting of the atom. The nineteenth was a "working" century, with astronomers committed to the hard labor of digging out the fundamental facts upon which later and more spectacular discoveries might be based.

Astronomy became a great collective enterprise. The work of one group of astronomers was often undertaken in the knowledge that it would supplement the research of another group at work perhaps thousands of miles away. As observation was added to observation and theory followed theory, the little jigsaw-puzzle pieces of a new conception of the universe were being put together.

The development of photography, discussed in previous pages, was to give astronomy a tool almost as important as the telescope. When photography first attracted general attention, about 1840, astronomers with vision began to realize the exciting possibilities of the new art in their own work.

An American, Dr. John Draper (1811–82) of New York University, was fascinated by the new art of photography. After some preliminary experiments, consisting of making portraits of his friends, Draper, in 1840, made a daguerreotype of the moon. The image was only about an inch in diameter and showed almost no detail. But it represented a genuine forward step, for it was the first real astronomical photograph.

Five years later two French physicists, Armand-Hippolyte-Louis Fizeau and Jean-Bernard-Léon Foucault, whose interest in

the speed of light we discussed in an earlier chapter, used Daguerre's method in photographing the sun. In 1850, with an improved daguerreotype process, George P. Bond at Harvard made a photograph of the moon through a 15-inch refracting telescope. This picture was considered to be so superior that it was exhibited in London at the International Exhibition of 1851.

In 1851, an Englishman, Frederick Scott Archer, invented the wet-plate process that was to serve astronomical photography for many years thereafter. It was not until about twenty years later that the dry-plate process was developed and astronomy really came into its own photographically. Much fine work had, however, been done before that time. With a special type of sun camera, the astronomers at the Kew Observatory had made daily photographs of the sun, with special reference to sunspots.

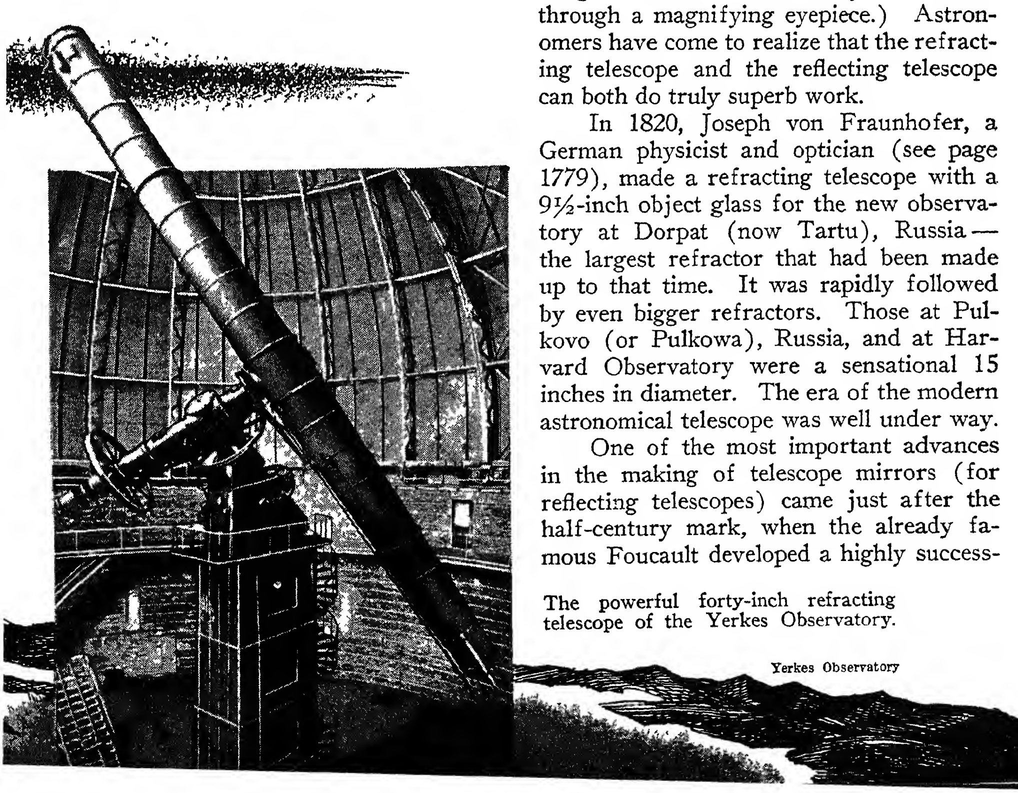
Today we know much of the universe only as it appears on the photographic plate. The human eye, at the eyepiece of the telescope, tires quickly and does not register the detail that imprints itself upon the sensitive emulsion of the modern photographic plate. Many beautiful and interesting celestial objects can be seen only with the eye of the camera in conjunction with the telescope. In fact, research astronomy has become almost entirely a photographic science.

The telescope-makers of the nineteenth century produced some of the finest instruments ever made; they laid the foundations of knowledge that made possible the superb giant telescopes that were to come later. Many of the telescopes that were constructed in the last half of the nineteenth century are still rendering valuable service and will probably continue to be used for a very long time.

There was considerable difference of opinion among astronomers and telescope-makers as to the respective merits of the refracting and reflecting telescopes. The refracting telescope brings rays of light (from a planet, say, or a star) to a focus through a combination of lenses, called the object glass; the reflecting telescope brings these rays to a focus by reflecting them from a concave mirror. (In both cases the image formed in this way is viewed through a magnifying eyepiece.) Astronomers have come to realize that the refracting telescope and the reflecting telescope can both do truly superb work.

In 1820, Joseph von Fraunhofer, a German physicist and optician (see page 1779), made a refracting telescope with a 9½-inch object glass for the new observatory at Dorpat (now Tartu), Russia — the largest refractor that had been made up to that time. It was rapidly followed by even bigger refractors. Those at Pulkovo (or Pulkowa), Russia, and at Harvard Observatory were a sensational 15 inches in diameter. The era of the modern astronomical telescope was well under way.

One of the most important advances in the making of telescope mirrors (for reflecting telescopes) came just after the half-century mark, when the already famous Foucault developed a highly success-



The powerful forty-inch refracting telescope of the Yerkes Observatory.

Yerkes Observatory

Spiral nebula, drawn by William Parsons, third Earl of Rosse.

ful method of silvering glass mirrors. Up to this time the making of mirrors for reflectors had been an arduous task with unsatisfactory results. The metal speculum (mirror), four parts copper and one part tin, used up to this time tarnished rapidly and sometimes even within two or three months the whole process of polishing and figuring the mirror would have to be done over again. This was a frightful nuisance, of course, and astronomers bitterly regretted the time that must be spent in keeping the mirror in shape. As it tarnished, the images of the celestial bodies became less and less clear. Foucault discovered that specula made of glass could be coated with silver, with extraordinarily fine results. True, silver also tarnishes in the course of time, but more slowly than the copper and tin alloys. The coating of the modern giant mirrors is often of aluminum, which is protected from tarnishing by a transparent film that forms when the metal is exposed to the air.

Later in the nineteenth century came the huge refracting telescopes. In 1888 a 36-inch one was installed at Lick Observatory on Mount Hamilton, California, and in 1897, a 40-inch at Yerkes Observatory, Williams Bay, Wisconsin. The 40-inch is still the largest refractor in the world and may be the upper limit for this type.

One of the most spectacular of the nineteenth-century telescopes was that of the Irish astronomer William Parsons, the third Earl of Rosse. In 1845 he completed a huge and unwieldy reflector with a metal mirror 6 feet in diameter. This was to remain the largest reflector in the world until the completion of the Hooker 100-inch telescope at Mount Wilson, in 1918. It required a fair-sized crew to handle Rosse's telescope; it had to be held up and adjusted by derricks and heavy chains. With this ponderous instrument Rosse made a great discovery. As he trained the telescope upon the northern sky, he observed a faint, cloudy object in the constellation Canes Venatici, the Hunting Dogs. The nebulous object appeared to be spiral in form, with long arms twisting around and hugging the center. Rosse had

discovered a spiral nebula, although he had no understanding of its real nature. To him it appeared to be a whirlpool of dazzling celestial radiance. He had no idea that it was actually a galaxy, not unlike our own Milky Way, composed of billions of stars more or less like our own sun.

The progress made in telescopy from Fraunhofer's little 9½-inch glass of 1820 to the almost faultless 40-inch at Yerkes in 1897 was due to the instrument-maker's ingenuity and patience. By the beginning of the new century there were more than forty telescopes over 15 inches in diameter, more than twenty over 20 inches and five over 30 inches.

The nineteenth century was a time of concentrated effort in observatories around the world to fill in the gaps in stellar astronomy. The exact positions of the stars, their apparent brightness, their motions and speed through the sky, their distance from the earth — this was information essential to the understanding of the universe.

Classifying stars in the order of their brightness

Anyone observing the night sky realizes almost instantly that the stars differ in their apparent brightness. (Apparent brightness, of course, is not at all the same as real or intrinsic brilliance, because the brightness of a star as we see it is greatly affected by its distance from us.) Hipparchus, the great Greek astronomer of the second century B.C., and Ptolemy of Alexandria, who flourished three centuries later, had arranged the stars roughly in the order of their brightness. The very brightest ones they called first-magnitude stars and the faintest ones visible to the naked eye, sixth-magnitude. Nothing more of great importance was done in this field until Sir William Herschel, at the end of the eighteenth century, classified some three thousand stars in order of their brightness. It was not until the nineteenth century that a comprehensive system of star magnitudes was worked out.

Shortly after 1850, N. Pogson, an assistant at the Radcliffe Observatory in Oxford, suggested that since a star of first magnitude is about 100 times as bright as a star of sixth magnitude, a universal scale of star brightness should be based on this difference. Pogson's ratio, the figure 2.512, represents the difference in apparent brightness (magnitude) between a star of the first magnitude and one of the second, between a star of the second magnitude and one of the third and so on. This system has been universally adopted. Today we say that the difference in brightness between successive magnitudes is about 2.5 times. Naturally, many stars have fractional magnitudes, since most of them are either fainter or brighter than the standard magnitude stars. The few stars brighter than first magnitude are given a minus number, based on the same scale. Sirius, for instance, which is the brightest star in the sky and much brighter than a standard first-magnitude star, has an apparent brightness of —1.6.

Many star catalogs were compiled, giving positions, magnitudes, amount of motion and so on. It is probable that the first catalog of this sort was made by Hipparchus about 150 B.C. Among the most important of the nineteenth-century catalogs is the BONNER DURCHMUSTERUNG (BONN CATALOG), compiled by Friedrich Wilhelm August Argelander at the Bonn Observatory about the middle of the century. It contains the positions and magnitudes of 324,198 stars. A photographic survey of the heavens was conducted at Harvard Observatory from 1886 to 1889. There have been many others.

Astronomers had long been curious as to the distances of the stars. In December 1838, the German astronomer Friedrich Wilhelm Bessel (1784–1846), director of the Koenigsberg Observatory, succeeded in making the first measurements of the distance of a star, 61 Cygni. This heavenly body, in the constellation Cygnus, the Swan, is a near-by star — comparatively speaking. Bessel was able to measure its distance by its parallax — its apparent shift against the background of the more distant stars, as observed from the two extreme points of the earth's orbit around

the sun. He found that 61 Cygni was about 50,000,000,000,000 (50 trillion) miles away. Bessel's achievement was not an easy one; he had worked many years to discover and perfect his method.

Some time previously, Thomas Henderson, the Astronomer Royal of Scotland, was doing the final work on his calculations on the distance of the southern star Alpha Centauri, which he had observed at the Cape of Good Hope. (Centaurus is a constellation of the southern sky.) In January 1839, less than two months after Bessel's announcement, Henderson disclosed the distance of Alpha Centauri as about 26,000,000,000,000 miles — just about half the distance of 61 Cygni. Only one star — with the exception of our sun — is closer to the earth than Alpha Centauri, and that is Proxima, a very faint star, also in Centaurus.

At about the same time Friedrich Georg Wilhelm von Struve (1793–1864), a German-born Russian astronomer, succeeded in measuring the distance of the brilliant star Vega. He, like Bessel, used the parallax method.

Spectroscopy solves many astronomical problems

A great deal of information about the brightness, position and distance of the stars had been obtained by astronomers with the aid of the telescope and the telescopic camera. But there were many other things they wanted to know that the telescope and camera could not tell them. What were the stars composed of, how hot were they, how fast and in what direction were they moving? In the nineteenth century there developed a science that was to give the answers to these questions and to many others — the science of spectroscopy.

In 1666, Sir Isaac Newton had proved that the light of the sun is a mixture of light of all the colors of the rainbow. He had proved this by placing a prism before a slit in a shuttered window and then allowing a ray of sunlight to pass through the prism into the darkened room. On the wall opposite the window there appeared a rainbow of light — the spectrum. In passing through the prism, the ray of light had been broken up — refracted and dispersed — into the various colors of which it was composed. This discovery of Newton's was to be the basis of much of our knowledge of the heavenly bodies.

How elements are identified in the spectrum

Today we know that in the spectrum — whether it happens to be that of the sun, a star, the atmosphere of a planet or a comet — we find the signature of the chemical elements of which that particular luminous object is composed. Any particular colored line or combination of colored lines always indicates the presence of a certain chemical element. When certain yellow lines are present, for instance, in a certain place in the spectrum, the scientist knows that sodium in incandescent gaseous form must be present in the source of the light.

In 1802, the English physicist, William Hyde Wollaston — a man who almost but never quite made several important scientific discoveries — produced a much finer spectrum than Newton's by using a narrower slit for the passage of sunlight through the prism. This gave him a more clearly defined band of color. Along this rainbow band he noticed many fine dark lines that he could not explain. He was interested to discover that these dark lines were not present in the spectrum of a candle flame.

Joseph von Fraunhofer, in 1817, produced a solar spectrum, still further refined, in which he observed some seven hundred of these dark lines that are now known by his name — the Fraunhofer lines. He did not know how to interpret them, but he did very carefully mark down their positions in the spectrum. In the course of his observations, he came to realize that the spectra of some of the stars were very much like that of the sun.

It was not until the work of the German physicist Gustav Robert Kirchhoff and the German chemist Robert Wilhelm Bunsen, about 1859, that the lines made sense.

American Museum of Natural History

Mars, as seen from its outer satellite, Deimos. From a painting by Howard R Butler.

They formulated the laws of spectrum analysis forming the basis of astrophysics — the science that deals with the composition of the heavenly bodies.

In 1864, detailed studies of the spectra of the stars were made by Father Pietro Angelo Secchi (1818–78) and by Sir William Huggins (1824–1910). Father Secchi was a pioneer in using the spectroscope — the instrument that is used in producing spectra — to survey the sky. He made spectroscopic studies of several thousand stars and grouped them into four main types according to their spectra. Huggins' work was of a more detailed nature — the study of about one hundred stars. In these celestial bodies he found many of the elements that are known on earth.

One of the most dramatic discoveries made with the spectroscope was the discovery, in the sun, of the element helium, then unknown upon the earth. In 1868 the French astronomer Pierre-Jules-César Janssen discovered what he claimed was a new element in the sun's spectrum. The British scientists Edward Frankland and Joseph Norman Lockyer showed that Janssen was right; they called the new element helium, after the sun — *helios,* in Greek. It was not until about thirty years later that helium was discovered on the earth.

For the devoted scientists who were working with the spectroscope, a whole new field had opened up and discoveries came thick and fast. Photographic spectra were made with the spectrograph, an adaptation of the spectroscope.

Another important use of the spectroscope was in determining the speed and the direction of motion of the heavenly bodies. In 1842, Christian Johann Doppler (1803–53), an Austrian physicist, had explained the effect of motion on the pitch of sound — the so-called Doppler effect. This explanation was to serve astronomers well in explaining also the effect of motion on the "pitch," or wave length, of light.

Explanation of the Doppler effect

When a train has thundered past you as you stand on the platform of a railroad station, the sound of the locomotive whistle is lower than it was when the train was approaching. Doppler explained this by the fact that as the train approaches in the distance, all the sound waves are compressed in front of the whistle and for this reason they are shorter and the sound is higher. As the train recedes, the wave lengths of sound are spread out behind the train and the pitch of the sound is lower.

In 1870, the French physicist Fizeau explained Doppler's theory correctly in its relationship to astronomical bodies. You will recall that the colors in the spectrum range from violet to red. If a star, as it moves through space, is approaching the earth, all the lines of its spectrum shift toward the violet end. If it is speeding away from the earth, the spectral lines shift toward the red. The Doppler effect, or the red shift as it is often called, enables astronomers to determine not only the direction in which a star is traveling — toward or away from the earth — but also its speed, which is determined by the amount of the red shift.

One of the great astronomical tri-

umphs of the nineteenth century was the discovery of the planet Neptune. After Uranus had been discovered by Sir William Herschel in 1781, astronomers had noted that the orbit of the new planet did not follow the path predicted for it. The deviations were not great but they were sufficient to indicate that some other heavenly body with considerable mass and gravitational force was pulling Uranus from its path. After all other possibilities were checked, astronomers came to the conclusion that Uranus' strange behavior must be blamed upon the pull of some other as yet undiscovered planet out beyond it.

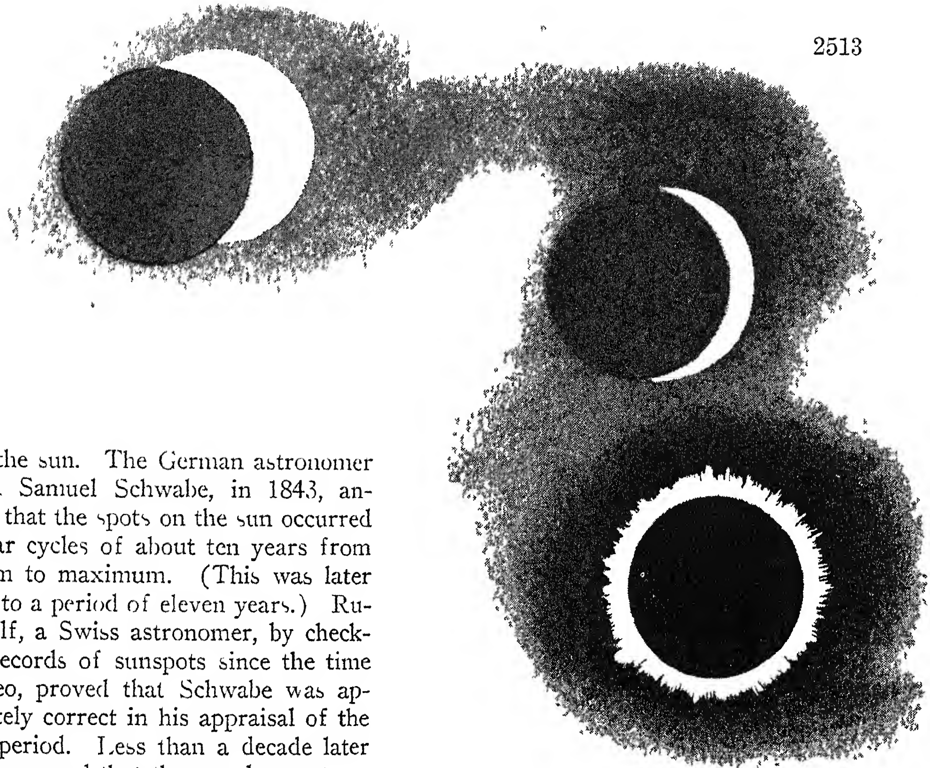
In 1845, a young Cambridge graduate, John Couch Adams (1819–92), found mathematically what he believed to be the position of the new planet. He asked Sir George Airy, who was then the Astronomer Royal of Great Britain, to check his findings. But Airy, knowing nothing of Adams and having no maps of that particular region of the sky, laid the calculations aside and did nothing about them. In the meantime, a young French mathematician, Urbain-Jean-Joseph Leverrier (1811–77), had attacked the same problem and had come to the same conclusion that Adams had reached. He sent his results to Johann Gottfried Galle (1812–1910), a German astronomer. Galle set to work immediately after receiving Leverrier's calculations, on September 23, 1846, and found the new planet in less than an hour. It was almost exactly where Leverrier had placed it, in the constellation Aquarius. Adams and Leverrier, in spite of Adams' bad luck, shared the honor of the discovery of the new planet, which was called Neptune, the name of the Roman god of the sea

There was one discovery in the nineteenth century that gripped the public imagination as well as the fancy of astronomers all over the world. The Italian astronomer Giovanni Virginio Schiaparelli (1835–1910), in 1877, observed some very faint and fine lines, apparently straight, on the surface of the red planet Mars. He called these markings *canali,* which, in Italian, means merely "channels." This was the beginning of a battle whose distant guns can still sometimes be heard. Were the canals artificial waterways constructed by intelligent beings, or could they be explained in some other way? Was there life on Mars? What kind of life? Many astronomers could not even see the delicate markings; others espoused the theory of life on Mars. When Dr. Percival Lowell of Boston built, in 1894, the great observatory at Flagstaff, Arizona, that bears his name, one of his chief aims was to make a study of the Martian canals

Astronomers had realized from very early times that spots often speckled the

A visitor from outer space — Donati's Comet (1858), from a drawing by Bond.

Yerkes Observatory



Three stages of a total eclipse of the sun.

face of the sun. The German astronomer Heinrich Samuel Schwabe, in 1843, announced that the spots on the sun occurred in regular cycles of about ten years from maximum to maximum. (This was later changed to a period of eleven years.) Rudolf Wolf, a Swiss astronomer, by checking on records of sunspots since the time of Galileo, proved that Schwabe was approximately correct in his appraisal of the sunspot period. Less than a decade later it was discovered that the sun does not rotate in various latitudes at the same speed. It turns more rapidly at the equator than in its northern and southern latitudes.

Eclipses of the sun by the moon were more carefully observed. For the first time the orange-red prominences of glowing hydrogen gas and the diamond-ring effect of Baily's Beads were studied and described. Eclipse expeditions were organized. Thus astronomers traveled to Italy, France and Austria in 1842 to observe the total eclipse of that year.

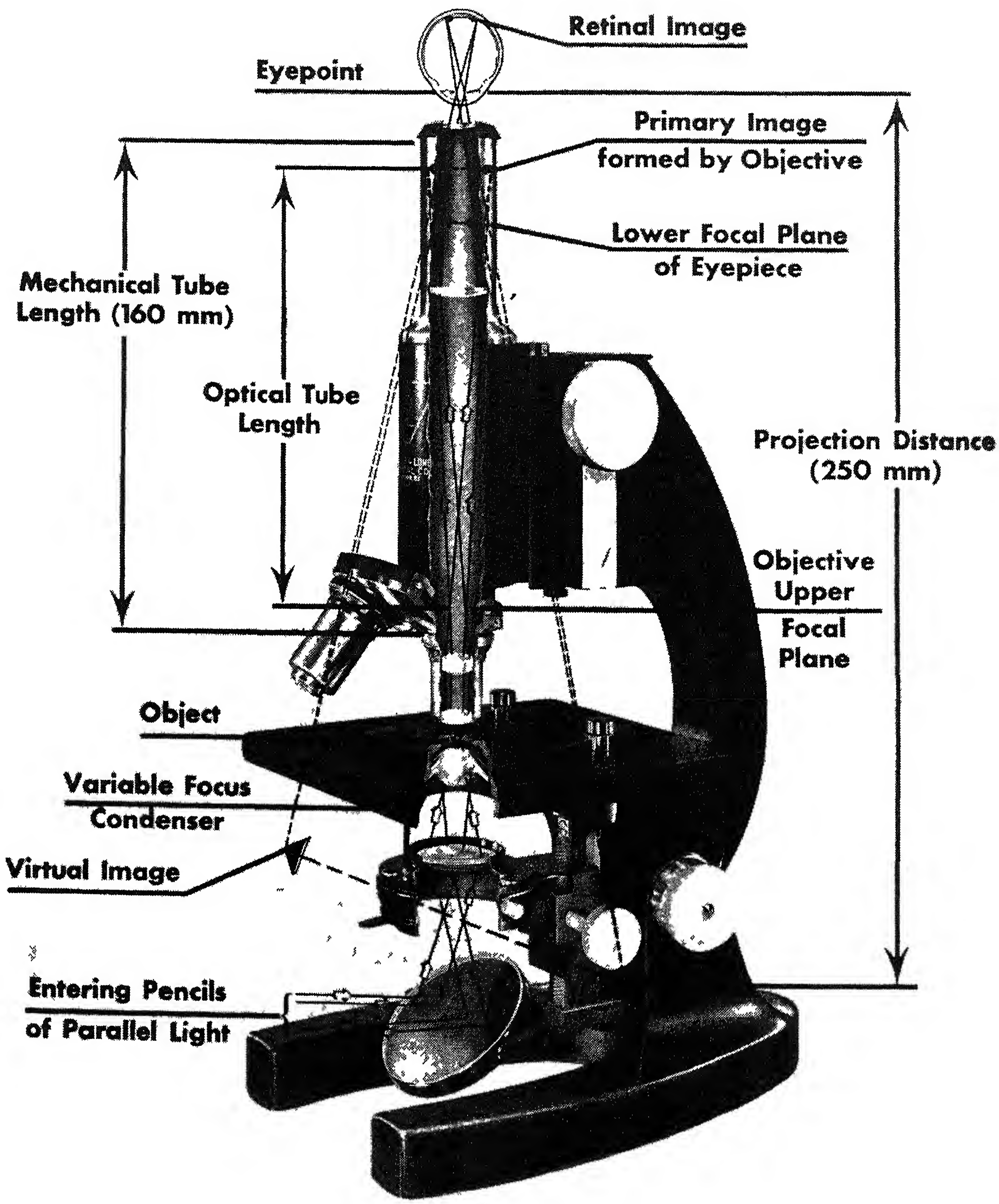
The sky is always a busy place, and the nineteenth century had its share of interesting spectacles. Comets came and went; perhaps none was more interesting than Donati's Comet of 1858, with its brilliant fan-shaped tail that eventually changed into two tails. Meteors — so-called falling stars — fell by the hundreds of thousands in the great November shower of 1833 and again in 1866. Astronomers began to suspect that meteor showers were somehow connected with the breaking up of great comets.

During the nineteenth century, astronomers became familiar with a hitherto unknown class of heavenly bodies — the asteroids, or minor planets, sometimes called planetoids For the most part, the asteroids move in paths between Mars and Jupiter. The first one to be discovered, Ceres, was found on January 1, 1801, the first night of the new century, by the Italian astronomer Giuseppi Piazzi. In the next seven years, three more were located, and in the last half of the century there were a number of such discoveries. It is probable that there are many thousands (one estimate is thirty thousand) of these small planets. Ceres, the largest, is nearly five hundred miles in diameter; the smallest ones are not much bigger than large rocks.

These are but a few of the developments that made the nineteenth century a great era indeed in the history of astronomical research — a period in which observational astronomy and theoretical astronomy alike reached full maturity.

SCIENCE THROUGH THE AGES is continued on page 2565.

The Modern Microscope



Bausch & Lomb

The microscope is one of the scientist's most important tools. It has added to his knowledge of inorganic substances; it has solved many problems involving the structure and functions of living things. Above is shown a modern instrument, with the path of light through it clearly indicated.

SEEING THE HITHERTO INVISIBLE

How the Microscope Magnifies Man's Range of Vision and Reveals a New World of Life and Movement

THE CHIEF INSTRUMENT OF MODERN SCIENCE

WE are all familiar with the simple magnifying glasses by means of which we may look at a part of a flower or a blade of grass and find the appearance greatly changed. The flesh on one's hand, when seen through such a glass, appears rough and coarse no matter how smooth and fine it may look to the naked eye. Yet these little instruments magnify but a few diameters. That is, an object seen under one of them seems to be only a few times larger than it appears to the unaided eye. Let us imagine, then, if we can, how great a change there is in the appearance of the same object when looked at through an instrument which magnifies many hundred times.

The microscope consists of a series of magnifying glasses mounted together in a suitable holder, the shape and adjustment of the different glasses being so related that they all work together to produce in the eye that looks through them an enlarged image of the object which is being examined.

It would be impossible to enumerate the services which this instrument has rendered and is rendering to mankind. Most of our knowledge of disease germs is directly dependent upon it. So also is our knowledge of the structure of the human body. The biologist would be helpless without his microscope to aid him in his study of the processes of growth in plant and animal. The laboratory of the chemist would be as incomplete without the microscope as it would be without the flasks and beakers.

All of these things are of great importance in our daily life. The knowledge of the physician and the biologist enable us to feed and care for the body properly; the work of the chemist enters into practically every process of manufacture. He determines what components shall enter into our food, the paint for our houses, the iron and steel and brass of which our buildings and machinery are built. In all of these his work is made possible by the microscope. The manufacturers and users of iron and steel are today relying very largely upon photographs of cut or broken sections of the metal to tell them its quality and reveal its defects.

By means of the microscope, objects about a quarter of a millionth of an inch in size can be distinguished from each other and photographed. By the ultra-microscope still more minute things are made visible and, though detail may be lacking, the number of particles can be determined. When the ultra-microscope is used with a camera device, we are able to record the motion of infinitesimal forms of life or energy which have hitherto been invisible.

We can perceive in a small piece of earth or in a drop of water extraordinarily minute vegetables belonging to a new and mysterious kingdom of life, and possessing every external attribute of an animal, such as the power of moving about and the power of feeding on other forms of life. We are able to trace in particles of matter, visible only through the ultra-microscope, strange motions, like those of a swarm of dancing gnats, hopping and jumping about together, and flying apart with astonishing rapidity; and in other varieties of matter we can distinguish strange processes of growth.

But the microscope humbles the pride of the human intellect, while extending the power of human vision. It penetrates beneath every simple surface of things to an underlying complexity, strange, marvelous, and awe-inspiring. When the microscope was still very imperfect, Huxley and Tyndall thought they discovered the secret of life in protoplasm, but a few improvements in the manufacture of glass for microscopic lenses revealed that there was much more in the simplest of cells than protoplasm, and, moreover, showed what complicated processes take place within the simplest cell. The field of knowledge is immeasurable, yet at each magnification of our powers of sight our field of vision widens. That is why microscopic science is so alluring. Take just one corner of it — microbe study; scarcely a thousandth part of the work required to be done there has yet been performed, so complicated, so varied, so enigmatical are the tiny shapes of life whose territory we are beginning to explore.

The modern microscope is one of the newest instruments of science. The true principles of it were not generally known by actual experiment until about 1880, when a noted German physicist, Professor Ernst Abbe (1840–1905), induced a German glass-maker, Dr. Otto Schott, to work with him in manufacturing a new kind of lens. Abbe, who had been studying the problem of optics since 1873, overthrew many of the theories of the microscope formed by his predecessors. He discovered what a microscope could be made to do, and he made it do it. He fixed the uttermost limits of vision of the marvelous artificial eye, and the recent instruments constructed in accordance with his ideas by Carl Zeiss of Jena and Bausch & Lomb in America, seem now to have reached those limits.

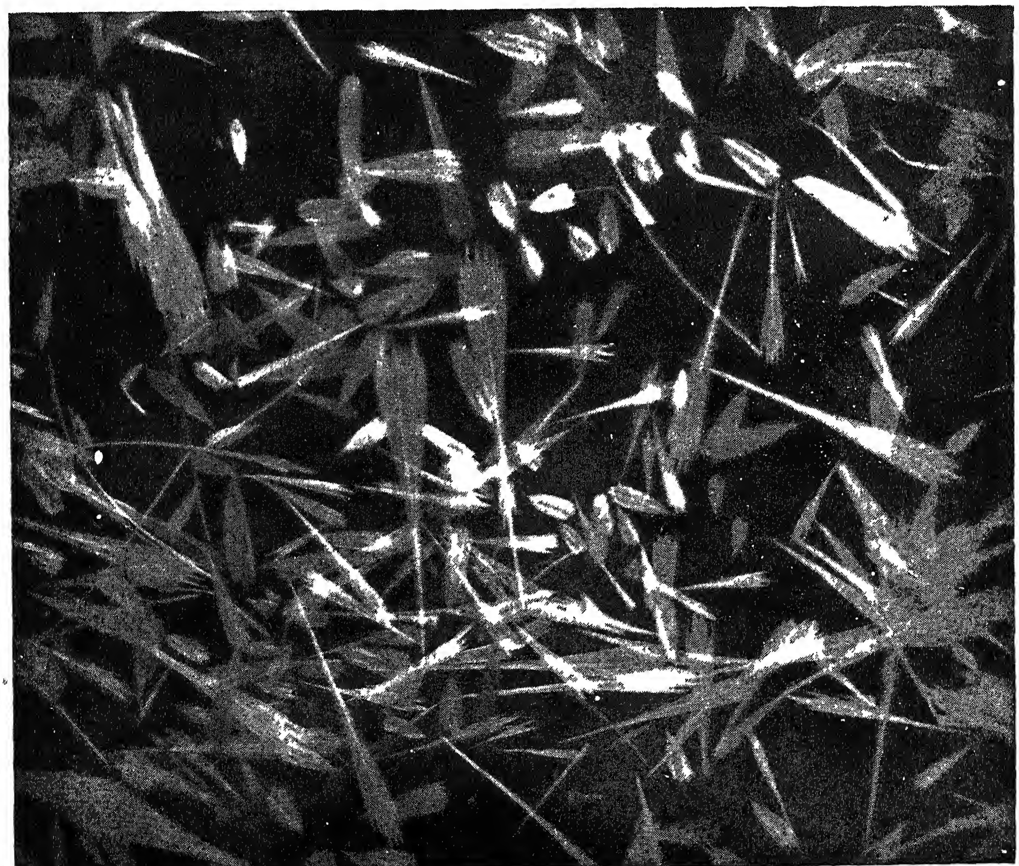
From the burning glass, via the spectacles to the microscope

The earliest extant example of a magnifying glass is the crystal found by Layard in his excavations of Nineveh. It is twenty-six hundred years old and consists of a piece of rock crystal, oval in shape and convex on one side, about a fifth of an inch thick, an inch and two-fifths in diameter, with a focal length of about four inches. It is now in the British Museum Whether or not the Greeks and Romans were familiar with magnifying glasses is a matter of discussion, but it seems probable, especially in view of the delicate engraving on many of their intaglio gems, that some form of lens was used by them to aid the eye. They could hardly have failed to have their attention called to the action of spherical glass vessels filled with water or the magnifying effect of the burning glass, known to have been used in the time of Socrates. The Arabians, too, in the eleventh century seem to have known something about the optical qualities of convex crystals, and it was possibly from them that Roger Bacon obtained his idea of making objects appear larger. With these lenses, he says, there could be devised "an instrument useful to old men and to those whose sight is weakened, for by means of it they would be able to see letters however small they are, made large and clear." It was in 1280, however, that an Italian, Salvino degli Armati of Florence, first brought out a pair of glasses in the form of spectacles. This is now the commonest form of the simple microscope — two magnifying glasses fitted in a frame so as to be used before the eyes, and it was left to two spectacle-makers, Hans and Zacharias Janssen, of Middleburg, Holland, who undoubtedly invented the telescope, by a simple modification in it to produce the compound microscope in 1590.

In its simplest form the microscope is an artificial lens, acting in the same way as the crystalline lens of the eye. As is now well known, the path of a ray of light is affected by the density of the transparent medium through which it passes. A simple experiment will show this. Fill a tumbler full of water, which is denser than air, and put an ordinary long lead pencil into it, and then look sideways at the pencil as it rests partly on the edge of the glass and partly in the water. The part of the pencil which rests in the water will seem to be broken off from the part that remains above in the air.

What happens is this: the rays of light, by means of which we see the pencil, are bent inwards when they enter the water. It we took a little glass globe and filled it with water, and then sealed it up, the water would bend all the rays of light that entered it. The rays would all be bent inward toward each other and would finally meet together at a certain point.

All that was required to discover the principle of magnifying glasses, spectacles, telescopes and microscopes was the knowledge that the curved surface of a globe of glass and water bends inward a ray of light, for the reason that glass and water form a denser medium than air. When this was found out, it was fairly easy to begin experimenting with various kinds



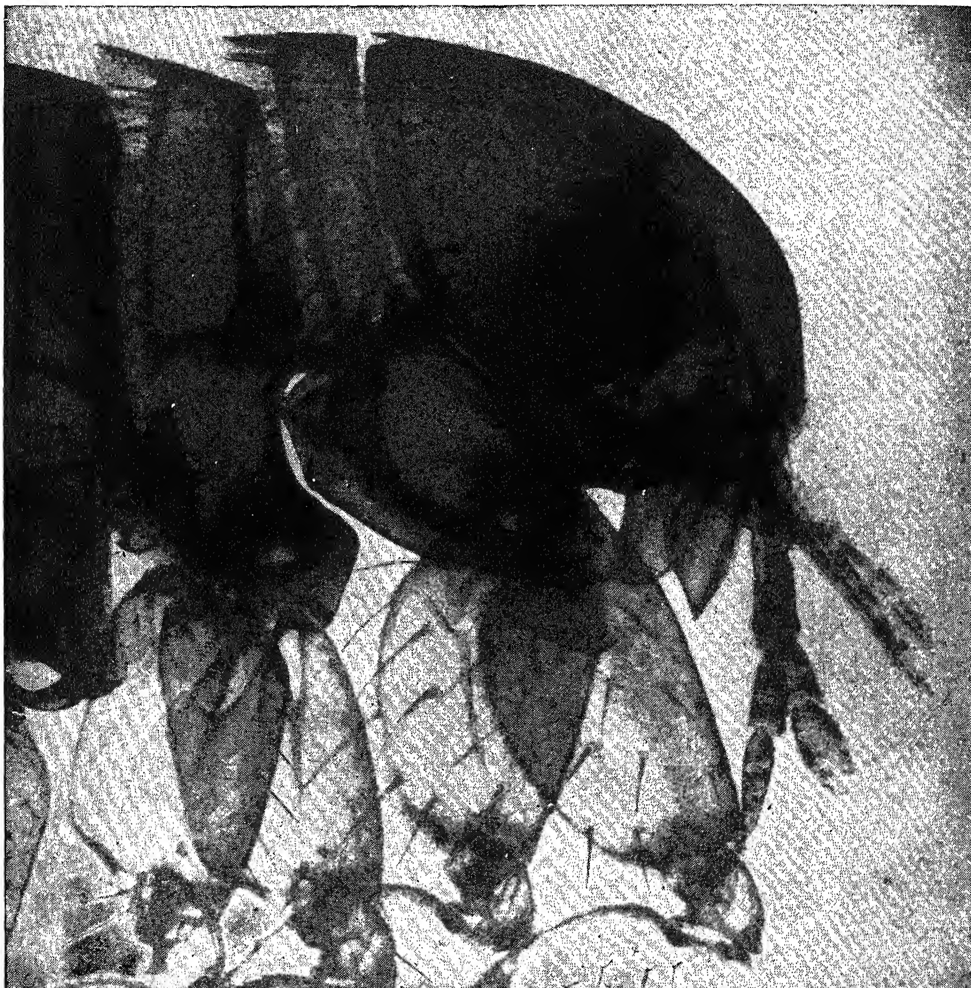
THE SCALES IN A SPECK OF DUST FROM THE WING OF A MOTH

of glass with different surfaces. This was done by some of the earliest spectacle-makers. They discovered that a convex surface, in which the smooth glass bulged outward, bent the rays of light inward; while a concave surface, in which the glass bulged inward, bent the rays outward. From this they worked out in practice a series of convex spectacle glasses for people suffering from long sight. and a series of concave spectacle glasses which remedied the defects of short sight.

Seneca, the learned tutor of the infamous Roman emperor Nero, noticed that if a glass globe was filled with water and placed on a written page, the letters would appear much larger than they really were; but no man in Europe, until the days of Roger Bacon, tried to understand *why* a globe full of water should magnify the objects behind it.

It is from this kind of intelligent search into the causes of natural phenomena that modern science was born.

We are in the happy position of understanding more about the matter than the Italians who amazed Europe in the thirteenth century by their "magic" glasses which improved the human sight, for we know more about the human eye than the old spectacle-makers. A principal thing in the human eye is the crystalline lens.

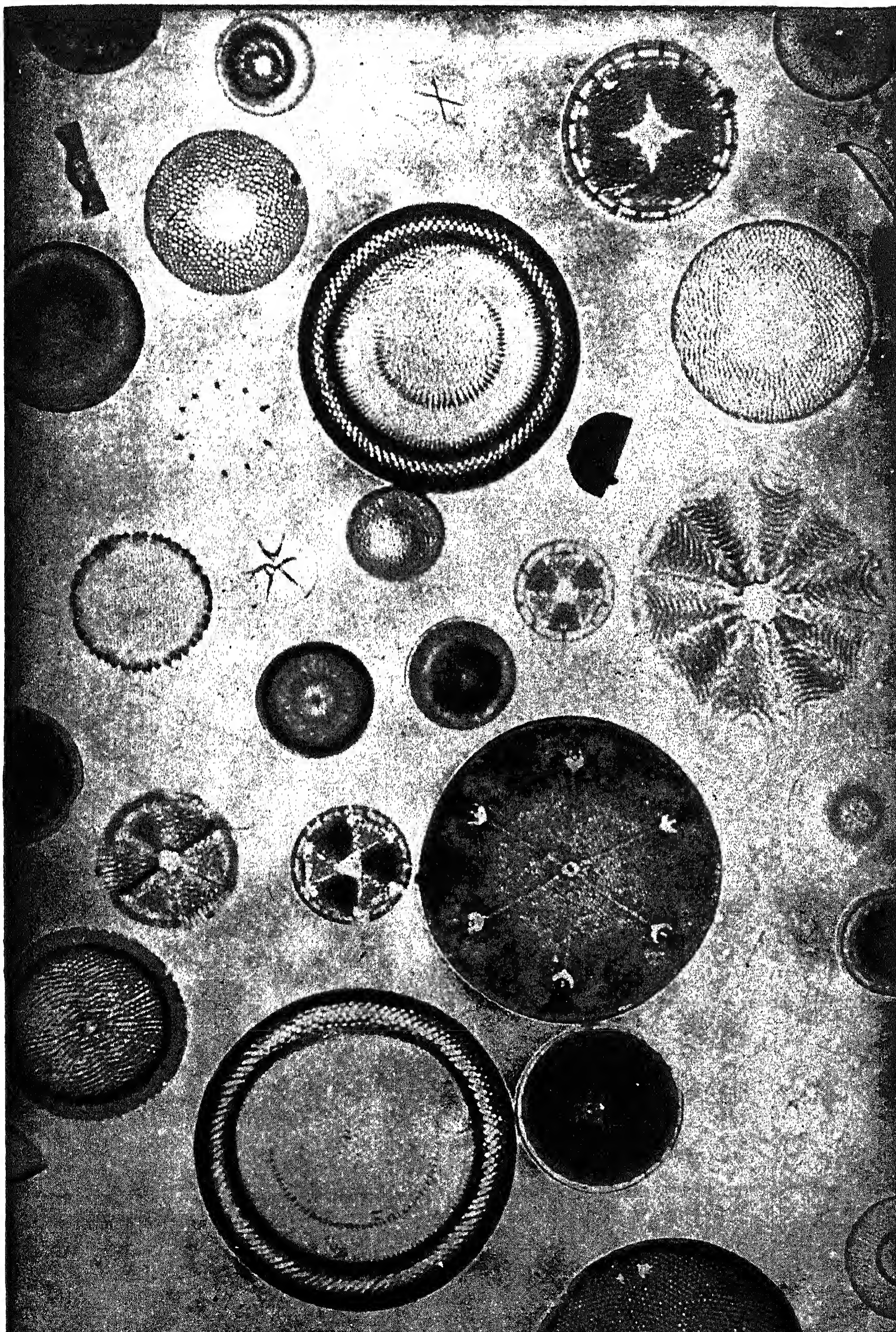


THE HEAD AND SHOULDERS OF THE COMMON FLEA

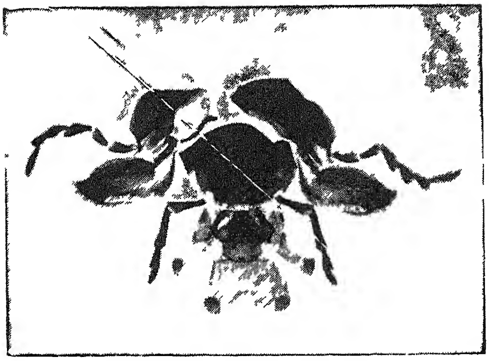
It is composed of perfectly transparent fibers, and has two rounded or convex surfaces like an ordinary magnifying glass. At some distance behind the lens is a transparent film of very sensitive nerves. This is the retina. It forms a screen at the back of the cavity of the eyeball, and it is coated behind with a dark colored matter.

Now, suppose we are looking at this page. It is flooded with light which it reflects much as a mirror does. The rays of reflected light spread out, and a certain number enter the pupils of our eyes. For convenience let us examine what takes place in the lens of one eye. As this lens has a convex surface, it bends the rays of light inward, bringing them together. The page at which we are looking is, of course, much larger than the little dark screen at the back of our eye, but the rays of light are so brought together in passing through the lens that when they strike on the dark screen they form a much-reduced image of the page.

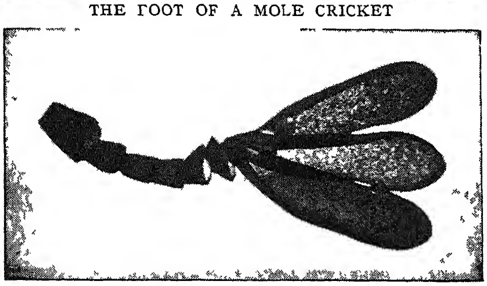
DUST-SHELLS THAT LIE IN THE OCEAN BED

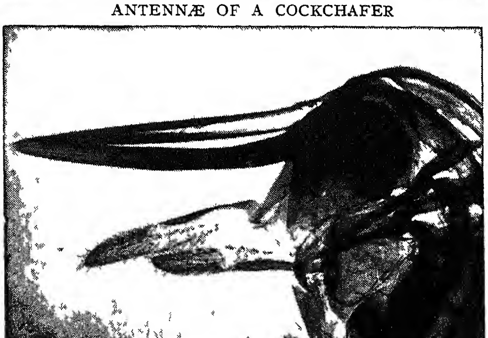


Diatoms are minute sea-plants, consisting of protoplasm with a shell-disc on each side of it, found in immense numbers in the sea, but so small that here they have been magnified 60,000 times.


THE TONGUE OF A CRICKET


THE FOOT OF A MOLE CRICKET


ANTENNÆ OF A COCKCHAFER


THE STING OF A WASP

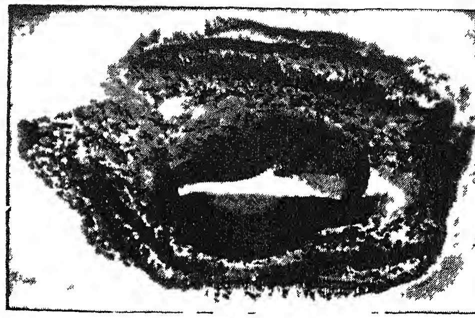
Thus the eye is a microscope, and attached to it is an exquisite piece of mechanism by which it is adjusted. Around the window or pupil of the eye is a kind of colored curtain — gray, brown, black or blue; this contracts and partly closes the window when the light is too strong, and expands and leaves a large opening when the light is weak. More important, from our present point of view, is the muscle of the eye, which is called the ciliary muscle. It presses on the top and on the bottom of the lens. In practically all perfect eyes the lens is flatter in front than behind. But when we look at very near things this flattish front is useless. We need a more microscopic vision, and the ciliary muscle at once gives us this, without any conscious effort on our part. The muscle contracts, and allows the lens to bulge out slightly in front and form a convex surface, like the surface of a magnifying glass. Our eye instantly acquires a stronger magnifying power, the rays of light are brought to the proper point at the back of the eyeball, and a clear image is formed of the object near at hand.

Often, when persons are growing old, the lenses of their eyes grow too flat in front; so they have to use a pair of spectacles with convex glasses when they want to see very near objects. On the other hand, people who are constantly poring over books, or using their eyes in other ways for the study of minute objects, suffer from the opposite defect. Their natural vision is excellent at a very short distance. Their eyes, however, cannot bring to a point the rays of light from distant objects, so a very indistinct and misty image of these objects is formed on the screen at the back of the eyeball. If we look at the glasses worn by short-sighted persons we shall find that they are hollowed out, or concave. The concave surface bends outward all the rays of light that pass through them; it makes them diverge, and thus corrects the too convex surface of the lens of the eye, and helps to bring the rays to the proper focus. The time comes in advanced old age when the limit of such help is reached, and no higher powered lenses avail to relieve the difficulty of vision.

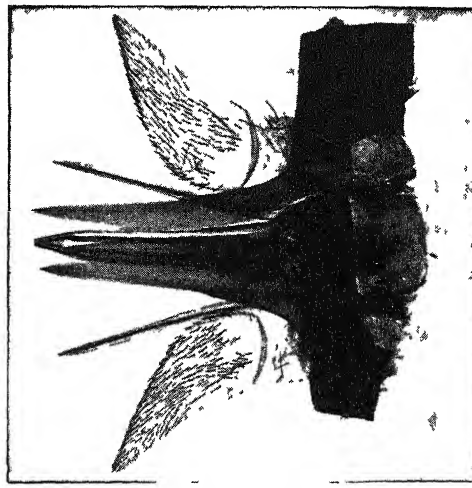
The word "focus" meant originally a fireplace. If a magnifying glass be held in a strong sunlight, it will bend the rays of light and make them meet in a small circle a little distance away from the back of the lens. The spot at which the rays meet will actually become a fireplace if a piece of paper or other inflammable material is held there. When the glass is used only for magnifying purposes, the focus is at the spot at which the rays bent by the glass meet and form a little picture of the object. This little picture is called the image In the earliest and simplest of compound microscopes, a magnifying glass was inserted at the end of a tube, and the tube was six feet long. Another lens was inserted at the opposite end to serve as an eyepiece.

When the microscope was pointed at a small object, the first magnifying glass collected the rays of light, and bent them, and sent them through the tube in a kind of narrowing stream of rays. All the rays met at the focus, and created an image in a certain part of the tube; and if the eye had been put there, the image could have been seen. Nothing, however, was placed at the spot where the rays met, so they crossed each other, and diverged again in a broadening stream. In this way they carried the image to the second lens, or eyepiece. This was also a magnifying glass, and it collected the broadening stream of rays, and again bent them and sent them towards the eye of the observer. Thus there were two processes of magnification.

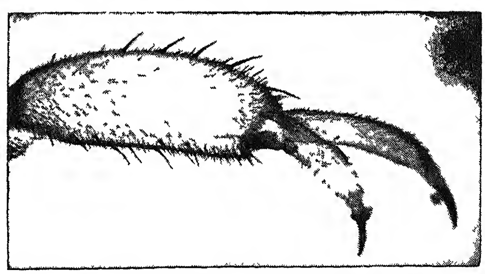
Such were the most primitive of compound microscopes; and the principle on which they were built is practically the same as that employed in the most powerful of modern instruments. There are two systems of lenses. One is placed at that end of the tube which is directed on to the object that is to be examined. This system of lenses is called the objective. At the other end of the tube, where the eye of the observer is placed, is a second set of lenses, which is termed the eyepiece The objective is the most expensive and the most powerful part of the microscope. It often costs as much as $150.



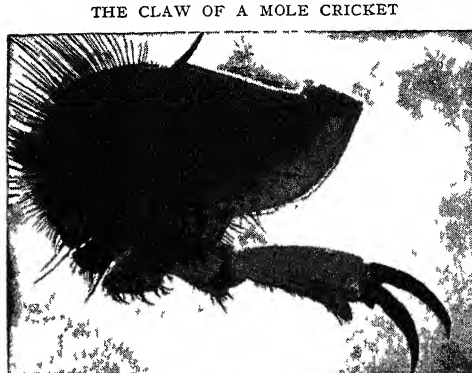
THE MOUTH OF A TADPOLE



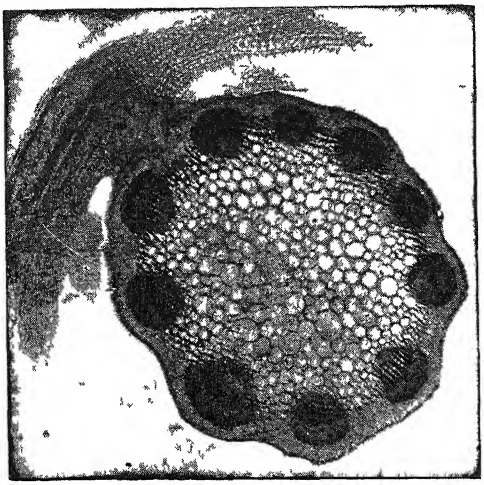
LANCES OF A BLOW-FLY

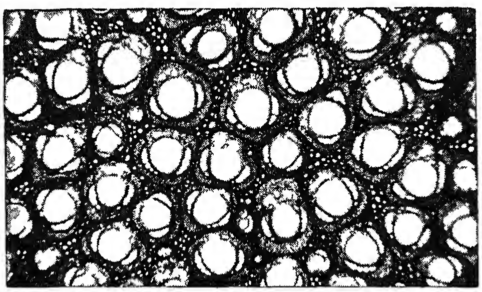


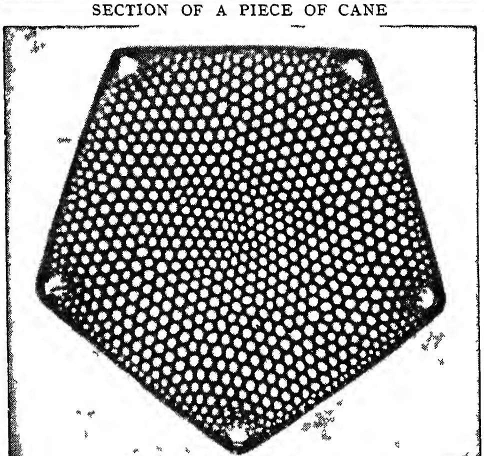
THE CLAW OF A MOLE CRICKET

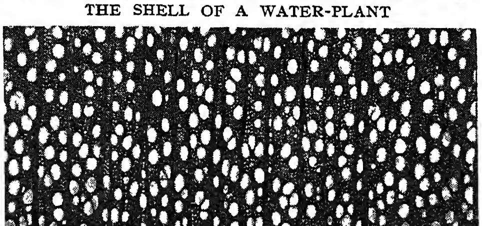


THE FOOT OF A WATER-BEETLE


SECTION OF A CLOVER STEM


SECTION OF A PIECE OF CANE


THE SHELL OF A WATER-PLANT


A SECTION OF APPLE-TREE WOOD

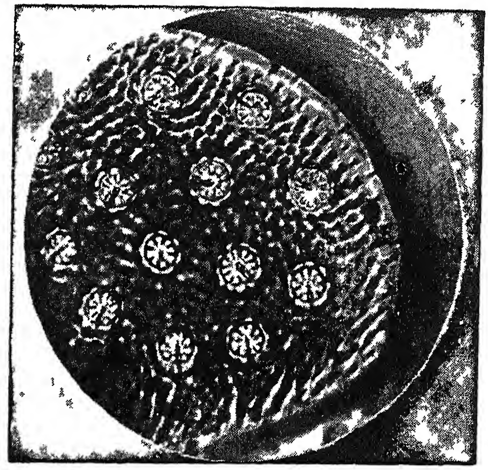
About six objectives are required with a first-rate microscope. They are detachable, and of varying powers and properties, and their use depends on the kind of work that is wanted, and the kind of object that is being studied The objective collects the rays of light which come from an object, it bends these rays inward, and sends them in a narrowing stream through the tube to the spot where they form an image Here they again part and travel to the eyepiece, where the image is still further magnified, and transmitted to the eye of the observer.

In all microscopes of this kind, only one eye can be used This is very fatiguing. Microscopic study is indeed the most laborious of all scientific pursuits. The physical strain of long-continued investigation, carried on with the highest powered lenses, is very great, and there is combined with it an incessant mental effort. Happily, F H Wenham discovered in 1860 a new way of arranging the microscope, which makes its use less wearisome. He designed a microscope with two tubes and two eyepieces The right-hand tube was straight and fitted with an objective; the left-hand tube was fitted into the side of the main tube When the stream of light-rays passed through the lenses of the objective, and emerged into the main tube, they struck against a prism. This was a piece of glass so shaped that it divided the stream of light-rays into two portions. The left portion passed uninterruptedly through the main right-hand tube, and so to the right eye of the observer; the right was reflected first to one side of the prism, and then to the opposite side; thence it was directed into the left tube of the instrument, along which it traveled to the corresponding eye of the observer. In this manner there were produced two images of the one object lying beneath the objective

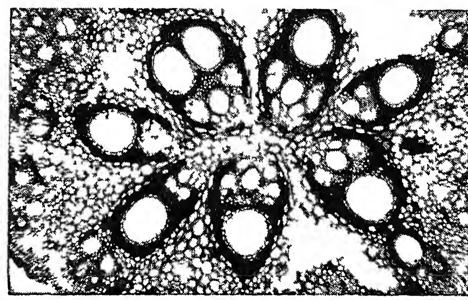
And now we come to a simple technical point which we hope will illuminate the explanation already given of the action of the compound microscope. There were two images in the Wenham's binocular microscope—one image in the right tube, and one in the left. Both these images,

it must clearly be understood, were invisible images They could only be seen by placing two pieces of paper at those spots in the two tubes where the two divided streams of light-rays separately came to a focus Naturally, the two tubes differed in length, the eyepiece of the left hand side tube being farther away from the object than was the eyepiece of the straight main tube This produced a curious effect The rays in the side tube had to travel farther, after they had formed an image at the focus and had there crossed and spread out again In thus traveling, they spread out more, and the result was that they produced in the left eyepiece a more magnified second image than that which the shorter rays produced in the right eyepiece This disagreement, however, was easily corrected by making the lenses in the left eyepiece lower in magnifying power than those in the right eyepiece

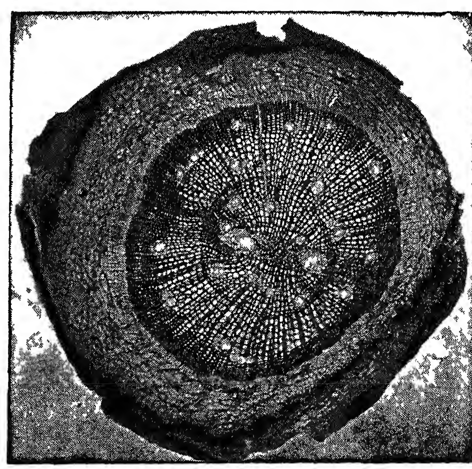
This type of microscope, however, failed to meet general approval as there was one defect which made it objectionable for long continued use Its convergent tubes, causing the two images to reach the eyes at an appreciable angle, introduced a severe strain on the eyes when the instrument was used for long periods, and research workers, while recognizing the real value of binocular vision through the microscope, were nevertheless forced to discontinue using it In recent years an improvement was effected and a binocular microscope was introduced by Leitz of Germany and later by Bausch & Lomb in the United States in which the tube length is identical for both eyes when set for normal vision, and the eye-tubes are parallel In addition a screw thread allows a slight modification of the tube length on one side to compensate for any possible variation in visual acuity of the observer. An adjustment is also provided for interpupillary distance so that the maximum impression of roundness and depth in the object can be secured At present a large number of research men in various fields of science are using the binocular microscope with marked success and its use is increasing.



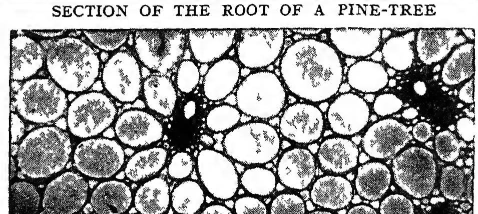
TERMINAL SEGMENT OF A FLEA



SECTION OF THE PEPPER PLANT

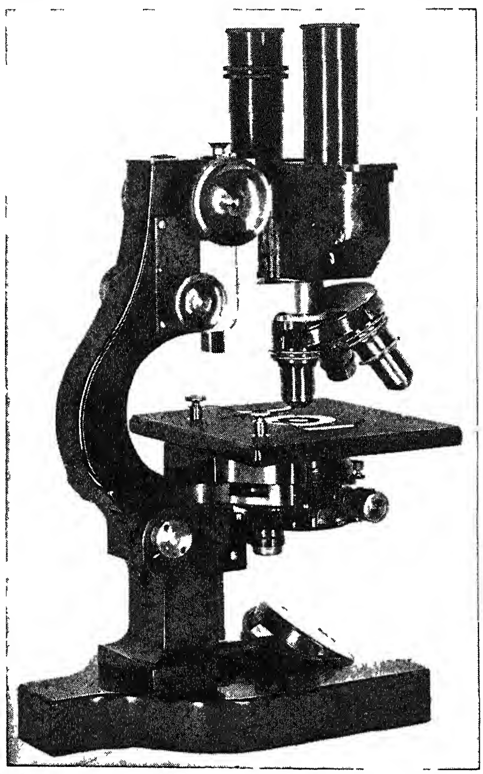


SECTION OF THE ROOT OF A PINE-TREE



SECTION OF A WATER-LILY

It may be safely predicted that the binocular microscope will continue to grow in popularity to the final exclusion of the single body type. Binocular instruments are not only more restful than monocular but they have some very valuable properties. They can give what is called a stereoscopic vision. A simple experiment will explain what this is. Set upright on a table a thin book about an inch thick and five inches in width. The back of the book, where the title is usually



BAUSCH & LOMB BINOCULAR MICROSCOPE

stamped, must face the observer, and be in an exact line with his nose, at a distance of about eighteen inches. Each eye will now be able to see a different side of the book; the right eye the right side, and the left eye the left side. When both eyes are simultaneously employed, the book appears to be solid, and to have depth. No confusion arises in the mind of the observer through the blending of two images of the same object, taken from two different standpoints. The same effect of depth is produced in the stereoscope, where two photographs, taken from slightly different angles, are simultaneously viewed through the instrument. The depth dimensions are revealed in a wonderfully vivid and distinct manner. By means of the binocular microscope in which this stereoscopic vision is obtained, we are able to examine the structure of minute living objects with perfect ease.

The early microscopes had two grave faults, which made them useless in the finest sort of work. One of these defects is called spherical aberration. As a lens has a curved surface, it is thicker in the middle and thinner at the edges if it is a convex lens, and thicker at the edges and thinner in the middle if it is a hollow concave glass. Let us take the case of a convex lens, with a stream of light-rays falling on its entire surface. The light-rays that pass through the thin edges will be bent in a different degree from those that pass through the thick bulging glass in the middle. Thus the rays will follow different paths, when they emerge from the glass, and they will not meet in a focus. That is to say, they will not produce an image, but only a wild and useless distortion of the object which it is vainly wished to magnify. So, before the compound microscope becomes of any practical use, this spherical aberration has to be corrected. Another lens of a different shape is fitted to the uncorrected lens, in such a way that all the rays are brought to the same focus. For example, a convex lens with two bulging curves has adjusted to it a glass one side of which is flat, and the other side of which is concave so that it fits exactly on to one of the convex surfaces of the uncorrected lens.

This, however, leads to another grave defect, which for many years was regarded as irremediable. Here we arrive at the fundamental realities of the science of the microscope. Hitherto, for the sake of simplicity, we have been talking about streams of light-rays. We have pretended that a light-ray was a simple, definite thing. Light is, however, not well understood. In some aspects it seems to be made up of particles, and in others of waves of different lengths.


THE HEAD OF A GADFLY


ANTENNÆ OF A MOTH


THE TONGUE OF A MASON-BEE

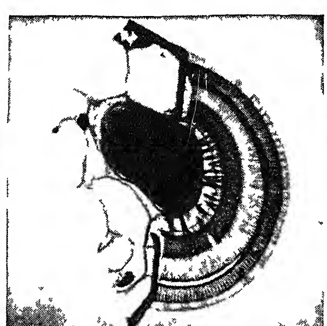
When a ray of light passes through a three-sided piece of glass, the different waves are separated; and when they emerge from the three-sided glass and fall against the screen, they form a band of rainbow colors. The same thing happens when they pass through any kind of lens, concave convex and so on. The white light is decomposed into a series of colors—violet, indigo, blue, green, yellow, orange and red. Each of these colors is separated from the other, and each makes a faint image of the object which is being magnified by the lens. This is called chromatic aberration.

The problem was to bring all the colored images together at one focus. Only by this means could the compound microscope be developed into a perfect instrument of scientific research. What was wanted was a variety of glasses of different densities, but, after about a hundred years of search, only two kinds of glasses could be discovered. These were crown and flint glasses. Flint glass is slightly denser than crown glass, and it has more dispersive power.

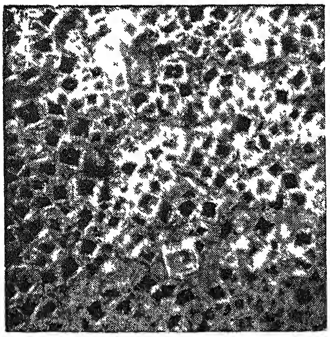
When this fact was understood, it became possible to correct two colors, by making a lens partly of flint glass and partly of crown glass. A piece of flint glass was ground hollow on one side, and made flat and straight on the other side: a lens of this shape is called plano-concave. A piece of crown glass was then made into an ordinary convex lens, with two bulging surfaces. The lower surface fitted exactly into the hollow space in the flint lens, and by cementing it in this position there was formed a doublet lens. The flat flint surface was placed above the object required to be magnified.

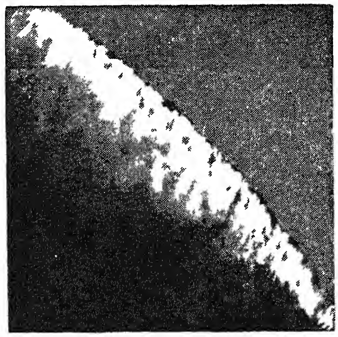
The light-waves coming from the object passed through the flint glass, and were, of course, broken into waves of colored light, each stream of colored waves being bent differently. A wave of red light is much longer than a wave of violet light, so the shorter violet wave was affected most. The various streams of colored light emerged, widely scattered, from the flint glass, and entered the crown glass, and here their paths were again once more altered.

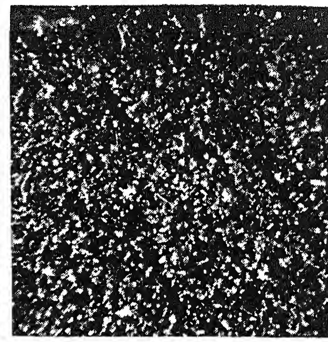

THE EGGS OF A MOTH


THE EYE OF A COCKCHAFER


THE TONGUE OF A FANTAIL FLY


CRYSTALS OF SALT


THE EDGE OF A KNIFE

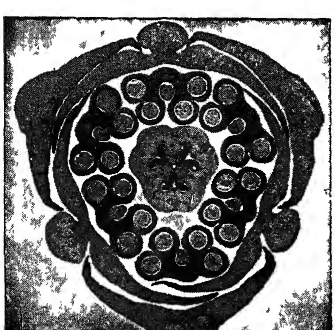

DUST ON A SHELF

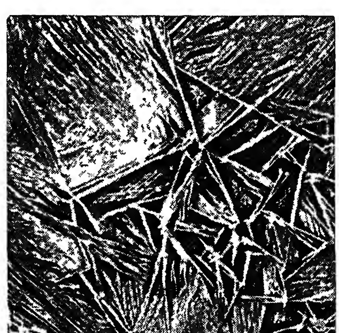
The result was that two streams of colored waves were at last bent somewhat in the same direction, and when they came to a focus they formed a two-colored image. The other streams of light-waves formed a series of fainter images, which were not only useless, but very confusing. Microscopes — called achromatic — were made that blocked out all the unfocused images, and left only the double-colored image to be transmitted to the eyepiece, and even this image was not free from defects.

So the matter remained until Professor Ernst Abbe, of Jena, and Dr. Otto Schott obtained from the German government a subsidy, and began a series of very important researches with a view to discovering new kinds of glass with just the density required to bring all the various colored waves of light to the same focus. The work of research lasted several years, and in 1886 the new microscope was put on the market. Not only did it contain a new glass, fluor glass, but it embodied some new and absolutely vital principles of optical construction at which Abbe had been working since 1873.

He was, in fact, the father of the modern microscope of extremely high power. He created a profound revolution in the mathematical theory of the instrument, and he worked out his theory on paper with such correctness that he was able to show exactly what the microscope could be made to do. He knew exactly what densities and curved surfaces were needed long before the things he wanted were discovered. Thus he was able to give directions to the men who worked with him at the practical part of the business. They had only to follow the lines of research he had worked out by mathematics. Abbe never claimed the subsidy offered by the government, for his plan of research was so well laid that the discoveries were effected before the money was needed.

The firm of opticians Zeiss & Co., of Jena, of which Professor Abbe became the head, has within recent years discovered a way to make use of the varying lengths of light-waves, instead of reducing them to a uniform focus. Red waves are about one-30,000th, while violet waves are only one-60,000th, of an inch in length.


THE BUD OF A LILY


CRYSTALS OF NITRATE OF POTASH


SEWING-COTTON AND FINE SILK

Wonderful adaptation of the microscope to the varying length of light rays

Now by means of the shorter violet waves objects can be distinguished which are twice as small as those which can be distinguished by the long red waves. The mean wave-length of light is one-47,000th of an inch, so that if the shorter violet wave could be used it would enable an observer clearly to distinguish minute things which, if viewed through the most powerful of microscopes in ordinary light, would only appear blurred together. Naturally, the shorter the light-wave which falls on anything and then bounds back from it, the more detail the wave will carry to the eye. This was clearly seen when a microscope was invented to be used only with violet light. Infinitesimal markings below the range of the wave-length of ordinary light were clearly perceived with lenses especially shaped and constructed to deal with light-waves only one-60,000th of an inch in length.

But, as is well known, there are very much shorter waves of light than the shortest of the violet. The ultra-violet light, however, is not visible to human eyes. Its waves are too short to make any effect on the dark screen at the back of our eyeball. What added to the difficulty was the fact that no known kind of glass was capable of being used to bend ultra-violet light in the way that ordinary light is bent by lenses made from crown and flint glass.

The latest advance in the construction of microscopes

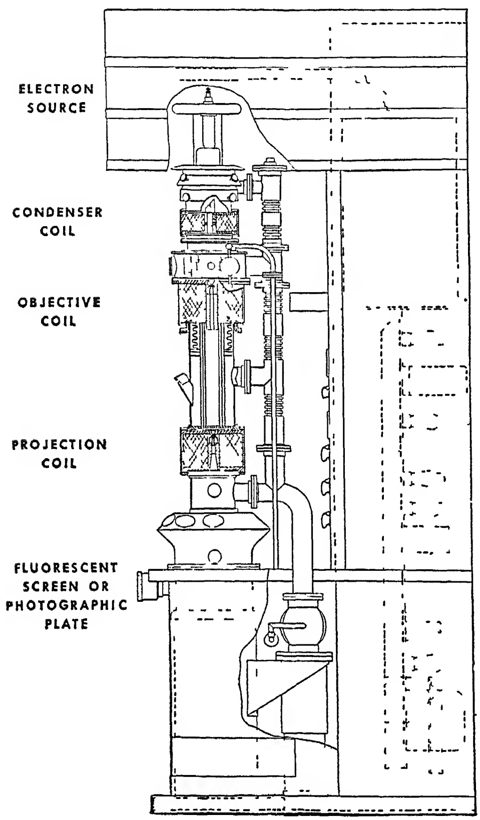
However, the Zeiss firm resumed its experiments, and succeeded at last in making lenses out of molten quartz. By means of these quartz lenses there was constructed a microscope which could be used with ultra-violet light. The image produced in the quartz eyepiece of the microscope was, of course, invisible to the human eye. Thus it was impossible for the observer to focus the lenses, so as to obtain an exact definition of the objects, which were sometimes one-240,000th of an inch in size. But by an ingenious arrangement this difficulty was overcome. The invisible image was projected from the eyepiece against a special screen, and on this it produced an image by the chemical action of the ultra-violet light. The microscope was then adjusted so as to give as much brilliancy as possible to the image, and a photographic camera was attached to the eyepiece, and a photograph was taken on a plate which had been made sensitive to ultra-violet light.

The microscope for ultra-violet light represents the ultimate advance practicable on Abbe's theory of the limits of the powers of the microscope. It is very important, however, to get a clear and definite idea of what this limit is. There is no practical limit to the magnifying power of a modern microscope. If a single dot, of any size whatever, is placed beneath the objective of a first-rate instrument, that dot will be magnified so that the eye can perceive it. There is a very minute animal called a rotifer, which is found in great numbers in ponds. Some kinds of rotifers are invisible to the naked eye. If, however, a man cared to go to a great and useless expense, he could probably have made a microscope which would magnify one of these rotifers to the size of a windmill. It would, however, look like a windmill in a thick mist. Little or none of the exquisite detail of the rotifer would be perceived — one would, indeed, scarcely be able to make out whether it was a windmill with whirling sails, or an animal surrounded with revolving organs.

The power that is much more important than magnification

There is something more important than magnification. This important thing is called "resolution". Supposing two lines are drawn so close together that one hundred thousand of them would only occupy one inch. A microscope that would "resolve" those two lines in ordinary light, that would make them stand away from each other so that they could be clearly seen, would be a microscope of very remarkable power. In fact, the resolution of lines ruled a hundred thousand to the inch is a power possessed only by the very best of modern microscopes.

In this respect a microscope can be compared with a telescope. If a good telescope is pointed at a distant star, it makes it seem smaller, if the finest telescope in the world is pointed at the same star, it makes it appear still smaller, and sometimes it makes it appear so small that the star is resolved into two minute points of light. The two minute points of light are the reality. It is a double star, and the stars are so close together, and at such a vast distance from our earth, that only an instrument of tremendous power can disentangle them from each other, and get a separate image of them.



SIMPLIFIED DRAWING SHOWING THE CONSTRUCTION OF THE ELECTRON MICROSCOPE.

The ultra-microscope

Tyndall, following out an idea of Faraday, used an ordinary kind of microscope, inferior to the best now obtainable, but he employed a new and curious kind of light. Tyndall was, we believe, the first man to discover why the sky is blue. He found that the white light of the sun as it passes through our atmosphere is broken up into the wave lengths of the colors of which it is composed. The blue light is scattered more than other colors.

This gave him the idea of using light in such a way as to reveal invisible particles of matter. By the use of Tyndall's method H. Siedentopf and R. Zsigmondy, of Gottingen, evolved the ultra-microscope. A small and extraordinarily intense beam of electric light is directed against the objects which it is wished to see. The waves of light strike against the objects and rebound, and are bent out of their path. They fly away in all directions, and some of them enter the lens of the microscope placed close above, and from the lens they are sent to the eyepiece. All that is required of the particles against which the light-waves strike is that they be capable of reflecting light.

The ultra-microscope is used in the study of oils, asphalt, paints, photographic emulsions, and numerous other things which are of great importance in our everyday lives.

The electron microscope

A new development in microscopy uses electrons instead of light waves. Beams of electrons, focused by the proper electric and magnetic forces, pass through the specimen to be studied and are again focused on a photographic plate which they affect. By using such methods it is possible to obtain magnifications up to 100,000 diameters. The electron microscope is, therefore, from 50 to 100 times more powerful than the strongest optical microscope.

Fields in which the electron microscope may be applied include biology, metallurgy, chemistry, ceramics, soil analysis, cements, paints and enamels, and textiles. The electron microscope photographed influenza virus for the first time; it showed the action of germicidal agents on individual bacteria; it revealed new facts on the texture of textile fabrics; it resolved new detail in the study of the surface structure of metals.

SUN-CLUSTERS AND NEBULÆ

Various Aggregations of Celestial Lights, from Star-Groups to a Feebly Luminous Nebular Fog

THE GORGEOUS DIADEM OF THE PLEIADES

WE have seen that double stars, or systems of two stars physically related to one another, are extremely common in the heavens; and, further, that with improved means of observation these binary systems tend to reveal a more and more complex nature. Systems of three, four or more stars, variously related, are known to exist, and some progress has been made in discovering the nature of their relations. But these small systems hardly prepare us for the astounding phenomena of star-clusters, which appear like supreme works of celestial jewelry.

The familiar acquaintance with the night sky, which country people have from childhood, accustoms the mind to the idea of large numbers of stars grouped together with architectural design in the constellations, and presumably related to one another by some physical bond. It is true that a very little learning is enough to show that this impression is largely erroneous, and that the grouping of the stars in constellations is principally no more than the optical effect of perspective. But the progress of astronomy is always finding actual relations between celestial bodies; many stars which appear to the naked eye or through the telescope as double stars are found to be related to each other. The casual observer is likely to imagine that the stars of the Big Dipper and of Orion belong together actually and are at the same distance. In some cases this is true, but not in most. Five stars of the Big Dipper do form part of a cluster through which the solar system is passing, but the others do not.

The most famous of all star-clusters has been known and honored from the earliest days. The Pleiades are perhaps the most illustrious of all heavenly systems; many primitive peoples have felt that they had some profound concern in the affairs of human life; and the phases of their rising and setting have been accepted as a calendar by toilers of the land and of the sea. And now the members of this vast group have been proved to be related in a real systemic union, by their possession of a common proper motion. The whole group of perhaps four or five hundred stars which make up the Pleiades is moving, almost like a flock of birds, in a south-east direction. Their apparent motion is very slow, about 5½ seconds a century. They keep the same relationship to each other, proving them members of one group.

They form, indeed, a most marvelous and majestic group. Their distance from us is now believed to be quite certainly about four hundred light-years, or four hundred times six trillion miles. Even at this enormous distance the chief star, Alcyone, appears of the third magnitude — a fact which proves it to be some two hundred times more powerful as a luminary than our sun. Sirius itself, being only forty-eight times as bright as our sun, would come but seventh in respect to brilliancy among the chief stars of the Pleiades, if it were situated among them. The principal stars of the group, six in number, are Alcyone, Electra, Atlas, Maia, Merope and Taygeta, all of which are of the fifth magnitude or brighter. The general form of the group, as seen by unaided vision, is well known, and is due to

the positions of these six stars, Alcyone occupying a central position, though probably not really exercising a dominant influence on the rest of the group.

The gorgeous diadem of resplendent suns forming the Pleiades

The number of stars actually belonging to the system of the Pleiades is at present undetermined. Over two thousand three hundred, down to the sixteenth magnitude, were counted in their vicinity in 1887, and four thousand stars appeared on a photograph of the region taken ten years later. But it is almost certain that only the most brilliant actually belong to the group. Most of the small stars appearing within its area are known, by the absence of proper motion, to be only visually connected with it, and to be actually at immense distances beyond it in space. Some of its brighter stars, on the other hand, have proved to be much nearer to us than the Pleiades; they display a proper motion in excess of that which is characteristic of the group, and are therefore known to be crossing the plane of vision between us and the Pleiades. Between four and five hundred stars have been especially studied and are now known to be part of the group. These, with perhaps many smaller stars not yet determined, and having Alcyone in their center, move together through the heavens, probably pursuing at the same time many and various mutual revolutions among themselves, forming subordinate systems within this gorgeous diadem of resplendent suns.

The nebulous material in which the Pleiades are embedded

Yet the spatial extent of the Pleiades is so vast, and their distances from one another so great, that even Alcyone, with its two-hundred-sun-power of brilliancy, only reaches the nearest of its great companions as a supremely bright star, some eighty or ninety times as brilliant as Sirius appears to us, and with a power almost sixty-seven thousand times less than that with which our sun reaches the distant orb of Neptune. So vast is this imposing system, so unimaginable its measurements.

Still, the Pleiades are near enough to afford us much very valuable information, not only with regard to star systems, but also concerning the relations between stars and nebulæ. The whole group is, as it were, embedded in enfolding nebulous stuff. Wisps, tails and clouds of nebulous material are apparently attached to various stars of the group, especially to Merope, around which they lie in bars, for the most part parallel with one another; to Maia, in a spiral form; to Electra, in a straight pointed bar directed toward Alcyone; and thickly rolled round Alcyone itself in fog-like clouds. But the nebula is much more comprehensive than these outstanding features would suggest. It involves not only the Pleiades, but a vast region around them on all sides. Several peculiarly interesting discoveries in regard to nebulæ and stars in general have been made in studying it. For instance, several long threads or ribbons of the luminous cloud-stuff are seen to string together lines of individual stars, uniting them like beads on a string. This seems to prove that lines of stars are really connected, and not fortuitously placed in their rectilinear position. Lines of this kind, either straight, arched or in beautiful regular loops and festoons, are common features of many clusters; and it had become evident to observers that these arrangements must be the result of real relations, before that opinion was finally established by the nebulous connecting lines in the Pleiades.

The bridging of the gap between open star-clusters and diffuse nebulæ

Clusters like the Pleiades, a group of stars physically related in a system, and combined with nebulous material, seem to bridge the gap between star-clusters and nebulæ. The stars in these clusters have, so far as they have been examined, been found to be of the "Orion" type, and have long been regarded as having newly arisen from the "shining world-stuff" in which they are still involved. Many astronomers, however, are now inclined to the opinion that the nebulous envelope is being formed by the expulsion of tenuous matter from the stars.

The forms of star-clusters are often exceedingly beautiful and interesting. Lines, either straight or forming loops, arches, streamers or more complicated figures, are traceable in many; a considerable number take the form of a half-open fan; others show by their names the resemblances suggested by their shapes. Thus, we have Præsepe, the "manger", which appears as a feeble cloud of light between two stars both of the fourth magnitude. These two stars were called by early astronomers the "asses". Globular

A PHOTOGRAPH OF A REGION IN THE PLEIADES, SHOWING ITS NEBULOUS CHARACTER

clusters are in many ways distinct from the rest, chiefly by their regularity of form and the usual absence of any real nebulosity. We shall consider them later. Colored stars are sometimes present, and in some cases various colors combined give great splendor and beauty to a cluster, as in a famous group in the Southern Cross.

Frequently a bright-colored star occupies a conspicuous and dominating position in a cluster of undistinguished stars, as in certain clusters which occur in Auriga and in Cygnus. Double stars occupy a central position in a cluster in Perseus. In Gemini is found a cluster containing within it a small, clearly defined cluster of seven or eight stars very close together. In Auriga there is a cluster in the form of a cross; on each arm there are two particularly bright stars, distinguished above all the rest. Similar devices of symmetry or effective placing are frequent. Well-defined geometrical forms, such as triangles and rectangles, are by no means uncommon.

Globular clusters are in general much more sharply defined than are the various irregular forms considered above. Occasionally the edges of the globe are clean and entire, but more often they are radiated by outward streamers and thread-like appendages, suggestive of an outward flow from the cluster, as if it might be a nest of bright new suns to be sent out gradually to occupy the spaces of the heavens. This may, in fact, be in some sense a true account of them, but it is certainly too early in the history of their observation to allow of any definite theory of this kind. The number of stars in globular clusters varies considerably, but a cluster usually contains many thousands of stars, in some cases

hundreds of thousands, and it is estimated by Dr. Harlow Shapley, from his study of many star-clusters made at Mount Wilson, that on the average the combined light of a cluster is about two hundred and seventy-five thousandths that of the sun.

The grouping of star-clusters in symmetrical arrangements

Very beautiful indeed are these wonderful balls of suns when seen in a great telescope. One of the most perfect is found in Centaurus, where it appears to the naked eye as a rather blurred fourth-magnitude star. In a good telescope this star becomes transformed into a vast sphere of brilliant, glorious suns, of which over five thousand have been counted by photographic means.

A similar but smaller cluster in Tucana is even more closely packed with bright suns, over two thousand being grouped within a boundary line of comparatively small radius. Another famous example is the globular cluster in Hercules, with at least fifty thousand stars which have been counted, and according to some authorities many millions of stars; this cluster sends out streamers and tentacles of stars to a distance which nearly doubles its diameter. In all these clusters the thickness of the crowding of stars increases in regular progression from circumference to center. The Hercules cluster is broken, as it were, by three dark rifts or lanes leading outward from a point not at the center, but to the southeast of it. The dark lines are found, however, from photographs of longer exposure, one of which is shown on page 4773, to be not really devoid of stars. They are strewn with small, faint stars, as, indeed, is the whole cluster, these small, faint stars being disposed apparently in really globular order. But there are also many bright stars, disposed in radial lines stretching outward in curves; and these are entirely absent from the dark lanes, which no doubt appear dark partly by contrast.

The stars in a globular cluster are usually graded according to brilliancy in an extremely methodical way. The arrangement of smaller stars in the center, with bright ones scattered over them, which we can trace in the Hercules cluster, prevails also in most, if not all, others.

The number of variable stars found in globular clusters is very remarkable, and as yet not understood. As many as a hundred have been found in a space in the sky that would be covered by a pin's head held as far away from the eye as it could be distinctly seen.

The Centaurus cluster is an example which is fertile in variables. Out of three thousand examined by Bailey of Harvard, nearly one hundred and thirty were found to be variable, for the most part within one and a half or two magnitudes, and sometimes less, down to an extent of half a magnitude; sometimes more. up to one which varied to the extent of five magnitudes. There seems to be no interdependence in the changes of the various stars in a cluster. Each varies apparently on its own account, as if entirely unrelated to its fellows. Miss Clerke thus comments on this extraordinary phenomenon:

The strange waxing and waning of stars in star-clusters

"No more curious spectacle is afforded by the heavens than that of a throng of seeming signal-lights waxing and waning every few hours under the sway, obviously, of some common law, yet with no trace of unanimity, some fading while their neighbors are on the rise, others stationary and semi-extinct, though only biding their time to enter upon a phase of renewed brilliancy, and none deviating by a hair's-breadth from the course of change individually prescribed for it."

The Hercules cluster is much more stable in light than the majority of globular clusters. But, on the whole, variability is a common feature of cluster stars. It is of a special type, consisting in long quiescent periods of comparative dullness, with short and quickly attained periods of brilliancy, the whole recurrent period being usually very short, and often measured in hours. For example, eighty-five variables have been discovered in a very fine cluster in Libra, almost all of which have a period of about twelve hours, although without

any apparent order in the times of occurrence. No physical differences, so far as can be ascertained, distinguish clusters rich in variables from those whose stars shine steadily.

The variation in the appearance of star-clusters determined largely by distance

The stars composing the various clusters are no doubt of different sizes, and are packed with different degrees of closeness. But at least a part, and probably a considerable part, of the differences which make one cluster resemble a heap of fine sand, while another cluster resembles a heap of much larger particles, is due to a difference of distance from the earth. For the same reason it is probable that many very distant clusters escape recognition, because they present the appearance of nebulæ.

We have already referred to the relations between open star-clusters and diffuse nebulæ. These two kinds of structure, as may be seen in the case of the Pleiades and of hundreds of other irregular clusters, are very frequently found together, merged in one another and united in a manner which leaves little doubt that nebulæ condense into stars or else that stars disintegrate into nebulæ.

The puzzling problem of the relationship between nebulæ and stars

The study of nebulæ is most fascinating, and is likely to prove very illuminating. It is remarkable that almost all forms and conditions of stellar existence have their close parallels in nebular existence, though of course in a vague and shadowy manner. Thus we have nebulous stars and planetary nebulæ, double nebulæ answering to double stars, variable nebulæ and there are even two great classes of elliptical and irregular nebulæ, corresponding to the globular and irregular forms of star-clusters.

Nebulæ abound in the heavens, and assume all kinds of odd and beautiful forms. There are tails, brushes, wisps, rings, fans, rays, triangles, squares, discs, spheres and many other shapes, but almost all hidden from unaided vision. The only one which is easily discernible is the great nebula in Andromeda (see pages 35 and 458).

The most easily seen and historical nebulæ in Andromeda

This is the supreme example, as far as apparent size and visibility are concerned, of the regular or elliptical form of nebula, and was well known to Al Sufi, the Arabian astronomer, in the tenth century. Nebulae of this type—spiral nebulae—are not true nebulae in any sense of the word, and the tendency today is not to refer to them as nebulae but as galaxies. They are in fact great spiral systems of stars very much like the Milky Way Galaxy in which our sun and solar system have their place. The "nebula" in Andromeda is perhaps the most beautiful and characteristic of all its type. The forms of spiral nebulae are usually quite definite, and brighten from outside to center. Dark bands, following the form of the ellipse, frequently intercept the disc of elliptical nebulæ; and a careful study of these bands, and of the dark lines or rifts in the various white nebulæ, has proved that they are essentially spiral in structure, though the appearance varies according to the inclination at which we see the nebula. A very comprehensive photographic survey of these nebulæ was inaugurated and partially completed by Professor Keeler, with the Crossley telescope of the Lick Observatory; his work was continued by Perrine and others and in almost all the photographs thus obtained the traces of spiral formation were manifest (see pages 28, 33, 1160, 1161).

The clearest and most beautiful of the spiral nebulæ

The various forms which are assumed are often very beautiful. The spiral is often double, two diametrically opposite branches being thrown outward from a central nucleus, sometimes in the direction of a second nucleus which is finally reached by one of the branches. The clearest and most beautiful specimen of this type is a nebula in Canes Venatici, called, from its appearance, the Whirlpool nebula. Two streams of luminous matter proceed from the nucleus at opposite points, and circle about it in spiral form in the direction in which the hands of a clock travel.

Both of these arms are uneven, and full of thick patches and bosses; they divide and again unite; and they give off tails which are turned away from the nucleus, like the tails of comets. One branch dies away to nothing; the other and longer gains a second nucleus at some little distance, after executing a complete curve about the primary nucleus. The whole appearance of the nebula suggests the combined effect of repulsive and rotatory forces, and has striking analogies with the structure of comets. The peculiar clearness of the Whirlpool nebula is due to the fact that to our vision it is scarcely foreshortened at all. In some nebulæ the spiral takes the form of an S, of which a good example is found in Pegasus. In this case, only parts of the complete spiral could be seen by means of the telescope, and various observers gave it very different forms, but its double spiral was revealed as soon as photography was applied.

The theory of kinship between spiral nebulæ and globular clusters

Almost all white nebulæ, with their spiral structure, are more or less globe-like bodies, and the theory that they are related to globular clusters has suggested itself to many observers. They all glow with continuous light. Their spectrum has not yet been satisfactorily interpreted, but it appears to support the theory that white nebulæ are, in fact, star-clusters, situated at such a distance that the light of their individual stars has become merged into a faint haze of soft light. Several difficulties, however, stand in the way of this theory. In the first place, the light is so faint that if the extensive clusters of nebulæ do indeed represent clustered stars, these stars must be at enormous distances apart. Moreover, if the light be due to merged starlight, the stars must be many times farther apart in the fainter regions of the nebula, and in that case the wider scattering should produce a different texture, and the individual stars should become separated to our view. But this never happens. The texture of nebular light appears exactly the same in all grades of brightness. And again, the clusters are almost all in the region of the Milky Way, while the spiral nebulæ are quite absent from this region. The cluster theory of spiral nebulæ is therefore difficult of acceptance.

These nebulæ are very large and very far away, and though it is not possible to determine their distance and size with exactness, recent measurements by Van Maanen at Mount Wilson on the spiral M. 33 in Triangulum give as its distance 6000 light-years and indicate that it has a diameter of about 60 light-years. That the spiral nebulæ, or at least the brighter central portions, are in rotation was proved by the spectroscopic investigations of Slipher and others, and now the measurements of the outlying nebulous condensations made by Van Maanen show clearly by direct evidence that the entire nebula is in rotation; the period for different nebulæ so far observed varies from 50,000 to 200,000 years. This may seem a slow rotation, but it means a very considerable linear speed on the periphery of such enormous bodies.

Gaseous nebulæ are far less numerous than white nebulæ, in the proportion of less than one to a hundred. They are all of irregular shape, of large size and of ill-defined outlines and, unlike the spirals, are found mostly in or near the Milky Way. Only parts of them become apparent to direct vision, even in large telescopes; but the dimmer parts and outer regions impress themselves easily on photographic plates, showing that their light is of far greater actinic than it is of visual power. It may almost be said that each irregular nebula is of a class apart, for they all display strong individual characteristics. Thus, the dominating feature in the great Orion nebula, sometimes called the "Fish-mouth", is a trapezium of bright stars with a bright central region about it.

Features of the great irregular nebulæ, the "Fish-mouth" and "Keyhole"

In the second greatest, the nebula in Argo, known as the "Keyhole", the most prominent feature is a sharply defined black opening, which has given its name to the nebula, gaping right in the center

of its brightest part. The Trifid nebula, in Sagittarius, is dominated by a bright multiple star situated just at the inner edge of one of the three petal-like lobes from which the nebula takes its name.

The most famous and resplendent of irregular nebulæ is undoubtedly the great Fish-mouth in Orion. It may be seen with an opera-glass as a silvery cloud round a multiple star in the sword of Orion. It was first attentively studied by Huygens in 1656, and from him the central bright part forming the so-called Fish-mouth became known as the "Huygenian region".

The part of the heavens named after a Dutch watcher of the skies

One of the stars of Orion is seen, by the aid of the telescope, to be multiple. The four chief component stars which constitute it form a trapezium, which is, as it were, the hub of this whole great nebula. These stars are of the fifth, sixth, seventh and eighth magnitudes respectively, and they are very close to one another.

They are actually embedded in the nebulous matter, as is confirmed by the spectrum of the multiple star, which shows very close nebular affinities. These stars have a small proper motion corresponding, at their computed least distance of a thousand light-years, to a real motion of about fifty miles a second; and it seems certain that the nebula shares this motion.

Photographs of this great nebula are very beautiful and impressive. The Huygenian region forms roughly a right-angled triangle, the base of which is broken to form the mouth of the sky-monster. It is most sharply defined along this edge, but with increasing photographic power this outline, too, becomes softened in vast clouds of fainter and far more extensive nebula. The whole formation has probably by no means been yet revealed, for its boundaries extend further with every new improvement in the instruments of research. It holds a central position in a wide region abounding in nebulæ, and it is likely that these will be found to be connected. At present the limits of the great nebula include a considerable portion of Orion's body. A large curved nebular cloud sweeps round the belt, and the Fish-mouth within it, and already distinct traces of a spiral principle working on an enormous scale have become evident in the whole.

The color of the nebular light is faintly green, and the Fish-mouth has an unearthly appearance when viewed in a good telescope. The mouth is the center of apparent nebulous rays running out from it in all directions, in forms strikingly like the rays of the solar corona; and these effluences go to make up the outer parts of the nebula. The close similarity of form between the corona and the great nebula is rendered the more significant by the fact that hydrogen and helium are found together in the spectrum of both, whereas in starlight, as one of these gases appears, the other regularly disappears from the spectrum.

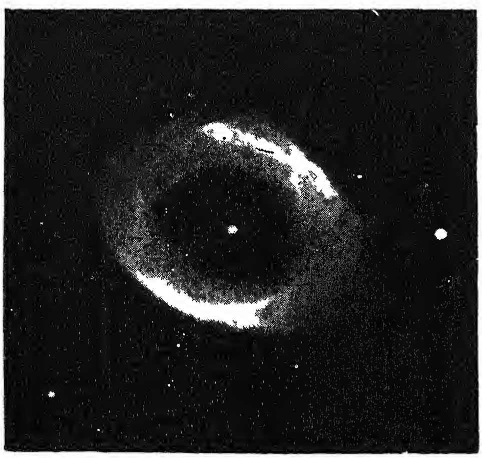
The strange colors of the great irregular nebulæ

All the irregular nebulæ have the same strange, greenish tinge. The Keyhole nebula in Argo, mentioned above, is a magnificent object, following as it does a procession of peculiarly bright and numerous stars. It extends over more than a square degree of the heavens, and more than twelve hundred stars are seen projected upon it. Some of these, if we may judge from the significant positions in which they occur, must be actually situated within the nebula. In the center and very brightest part of the nebula is a black opening in the shape of a keyhole, and exactly upon the edges of this dark cavern are seated four bright stars. No stars whatever can be seen within the keyhole.

It is often not easy to say whether an object should be regarded as a star with filmy appendages or as a nebula with a stellar nucleus. A true nebular star is surrounded by a luminous halo which cannot properly be called an atmosphere, since it is both self-luminous and inordinately extensive. Thus, the halo of the first nebular star to be discovered is of an extent sufficient to fill a space twenty

seven thousand times greater than that contained within the orbit of Neptune. The stellar nuclei are often compound: one in Auriga consists of three stars set in the form of an equilateral triangle, placed exactly in the center of a small circular nebula. Another in Orion also consists of three stars, respectively yellow, purple and white, embedded in a nebulous halo.

Nebulous stars with compound nuclei are connected by transitional forms with double nebulæ. Increasing instrumental power tends, however, to merge nebulæ, formerly supposed to be double, into single nebulæ; whereas stars formerly supposed to be single are more and more divided



THE ANNULAR NEBULA IN LYRA
From a photograph by G. W. Ritchey

into compound systems by the advance in optical efficiency. Yet the clearly defined double nuclei in the spiral nebula in Canes Venatici, referred to above, and others of similar constitution, lead us to a belief in the real existence of double nebulæ. Sir John Herschel made a special search for these objects, holding that they might represent the early stages of double stars. Compound nebulæ have been found in all combinations similar to those of double stars. Thus, we find a single primary nebula with two satellites; a single satellite attending two primaries; three fairly equal companions; doubles of various forms, such as elliptical, globular, lenticular; and other combinations. A curious example in Pegasus consists of three small nebulæ placed at the angles of a triangle whose sides are sketched by filmy nebulous bands, and in the midst of this figure is a bright double star.

Planetary nebulæ usually appear elliptical in shape, and are probably really spheroids. They contain a stellar nucleus situated apparently within a disc, the latter having a more or less complicated form often suggesting the envelopes in the head of a comet. The largest of planetary nebulæ, known as the Owl, was described by the younger Herschel as "a large, uniform, nebulous disc, quite round, very bright, not sharply defined, but yet very suddenly fading away to darkness". Later, two stars were observed within it, each in the center of a dark cavity, with a bridge of luminosity between them, giving to the whole a singular likeness to the face of an owl. But the stars have since become invisible, being replaced by a single bright star on the central bridge of light, and dominating the whole nebula

Annular or ring nebulæ are often very beautiful. The most perfect, situated in Lyra, appears as a hoop of filmy light surrounding a star. The hoop is neither even nor circular. It is oval in form, and brightest at the extremities of its shorter axis, fading considerably at the ends of the longer axis. Photography shows the center to be covered with a filmy veil, and it is believed that the ring is the effect of a tenuous globe seen in perspective, through which the central star shines unobscured.

It is expected that knowledge of the nature of nebulæ will be gained principally by the spectroscope. The general results of spectroscopic study have revealed conditions of great rarefaction and of very low temperature. It is also known that nebulæ are of excessive tenuosity, because of their enormous volume, together with their inability to produce large velocities in the stars in their vicinity.

Calculation has shown that the Orion nebula, at the lowest estimate of its size, if composed of matter one million times rarer than our atmosphere, would be capable of producing great velocities in all stars near it. But no sign of any such

effect is found among all the stars of the region; indeed, the stars about Orion are singularly fixed The density of this nebula must therefore be immeasurably less than that of air in a vacuum tube

The investigations of the diffuse nebulæ made by E Hubble at Mount Wilson show that these galactic nebulæ are too cold to be self-luminous in the ordinary way and that they derive their light either by reflection or by excitation from the stars involved in them or closely associated with them. These stars are of the very hottest types and produce the nebulous luminosity in a way not yet clearly understood.

Finally must be mentioned that large class of nebulæ which are not seen, namely, the dark nebulæ, the existence of which in large numbers has been so convincingly proved by the long labors of the much lamented Barnard His observations and photographs of many regions containing these dark nebulæ show that they are diffuse masses, often of enormous volume, consisting probably of cosmic dust or fine particles and obscuring the light of the Milky Way which lies behind them And more recently Father J. G. Hagen, the Director of the Vatican Observatory, has published a long list of smaller dark nebulæ which are not restricted to the region of the Milky Way but are found in all latitudes even up to the galactic poles. These nebulæ, like those photographed by Barnard in the Milky Way, can be discovered only by the fact that they cut off the light of the more distant stars and thus become known to us not by their light but by their shadows.

INTERNAL MOTIONS OF MESSIER 81 IN 1300 YEARS
From a photograph taken with the 60-inch reflector at Mount Wilson Observatory

A DARK CURTAIN OF SWIRLING GASES

Mount Wilson Observatory

The Horsehead Nebula, in the constellation Orion. It is dark, unlike many other nebulae, because there are no stars near by to set it shining, either by reflection or by the process called fluorescence.